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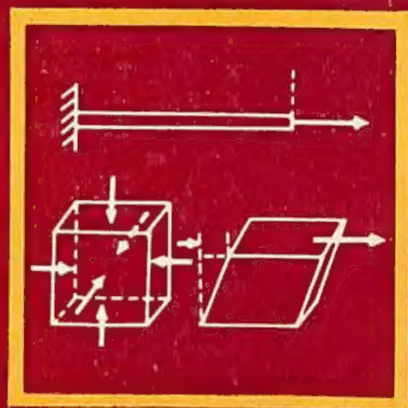
Revision in PHYSICS 2






A K BHARGAVA

SYMBOLS, ABBREVIATIONS AND UNITS

Symbol	*Quantity*	*Scalar (S) or Vector (V)*	*SI unit*	*Defined in*
A	Ampere	Base SI unit	–	D.1.5, D.18.17
A	Area	S	m^2	—
	Mass number	S	—	D.11.7
	Power of accomodation	S	m^{-1}	D.17.9
AC	Alternating current	—	—	D.20.13
B	Magnetic induction	V	$NA^{-1}m^{-1}$	D.19.20
c	Specific heat capacity	S	Jkg^{-1}	D.13.4
cal	Calorie	CGS unit of heat	—	D.13.2
°C	degree Celsius	Derived SI unit	—	D.12.13
C	Heat capacity	S	J	D.13.5
C	Coulomb	Derived SI unit	As^{-1}	D.18.5
C, C_1, C_2	Centre of curvature	—	—	D.15.6, D.16.17
d	Density	S	kgm^{-3}	D.9.6
D	Dioptre	Derived SI unit	m^{-1}	D.16.29
DC	Direct current	—	—	D.20.12
e	Elementary charge	S	C	D.18.3
E	Electric field strength	V	NC^{-1}(Vm)	D.18.8
E	Earth wire	—	—	D.21.7
EMF	—	S	V	D.18.19
f	Focal length	S	m	D.15.9
f-number		S	—	D.17.16
$f_1(f)$	Primary focal length	S	m	D.16.24
f_2	Secondary focal length	S	m	D.16.25
°F	degree Fahrenheit	FPS unit	—	D.12.13
F	Focus	—	—	D.15.8
F	Force	V	N	D.4.3
$F_1(F)$	Primary focus	—	—	D.16.21
F_2	Secondary focus	—	—	D.16.22
i	Angle of incidence	—	radians, degrees	D.14.15
I	Light intensity	S	—	—
I	Electric current	V	A	D.18.16
J	Joule	Derived SI unit	Nm	D.5.2
kcal	Kilo calorie	CGS unit of heat	—	D.13.3
kWhr	Kilowatt hour	Derived SI unit of energy	J	D.21.4
K	Kelvin	Base SI unit	—	D.1.5, D.12.4
l_f	Specific latent heat of fusion	S	Jkg^{-1}	D.13.9
l_v	Specific latent heat of vaporisation	S	Jkg^{-1}	D.13.10
L	Latent heat	S	J	D.13.8
	Length	S	m	D.1.5
L	Live wire	—	—	D.21.5
m	Magnification	S	—	D.15.19
m_a	Angular magnification	S	—	D.17.26
m, M	Mass	S	kg	D.4.2
n	Refractive index	S	—	D.16.6
N	Neutral wire	—	—	D.21.6
O	Pole	—	—	D.15.5

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Revision in PHYSICS 2

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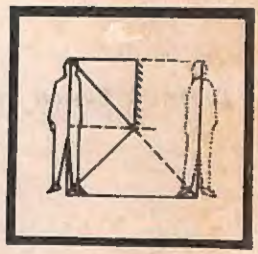

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Preface

Revision in Physics is a two volume book written primarily for Class IX and X students offering the All India Secondary School Certificate and Delhi Secondary School Certificate Physics Course A paper. It is an excellent reference book for students of ICSE, and for those appearing in the U.P., Rajasthan, Haryana and other Boards, as their syllabi have a lot in common with the CBSE syllabus. It is specially useful for those appearing for the Junior Science Talent Examination.

This book attempts to introduce students to the vastness of physics and its numerous applications. Broadly speaking physics is the science of matter, its structure, properties and behaviour. The physicist is always in search of the basic ideas to unify his vast subject, ideas that permit him to understand the working of atoms, molecules, stars, etc. Of late physics and its ideas are finding more and more applications in life sciences. It is being increasingly felt that to solve the problems of life sciences a sound knowledge of physics is a must. Because of the wide applicability of the principles of physics, even those who do not plan to pursue a career in science will benefit if they possess an understanding of the basic laws of physics.

Physics has numerous applications in our day-to-day life in the world around us. We firmly believe that many of the principles of physics can be easily understood through numerical problems based on examples drawn from diverse fields such as sports, life sciences, engineering, etc. When you see that a law can be applied successfully to solve apparently unrelated problems in many diverse disciplines, you realize that not only is physics a useful subject but also offers a promising career.

The book does not follow the conventional format of presentation. The concepts in each chapter are introduced through precise definitions supplemented by notes and diagrams. Each concept is usually divided into five parts; what the given quantity represents; nature of the quantity: how it is algebraically and graphically represented; its definition; and the associated mathematical relationships. The other important points associated with the concepts are given separately under 'Notes'. We expect that this kind of separation will bring conceptual clarity.

The theory and its applications are developed with the aid of solved numerical problems. Examples are drawn from Indian history, world history, sports, life sciences, and everyday incidents. *An attempt is made to draw as much data as possible from Indian background.* The problems are written in such a way that the first few lines provide general information about the event. This way of introduction will enhance general knowledge of the students and simultaneously make physics interesting. In most of the problems taken from day-to-day life happenings, the numerical values are very close to those occurring in real life. While using mathematical

equations numerical values are always accompanied by the appropriate units. We expect that this kind of approach will minimise the possibility of committing mistakes in units. At the end of the book are provided theory questions, following the CBSE examination pattern.

I am thankful to my colleagues for their interest in this book. Dr. S.C. Bhargava took a special interest right from the foundation stages till the end. I express my sense of appreciation to my wife Renu Bhargava for her forbearance and her willingness to sacrifice part of her social life. Without her active cooperation this book would not have been possible. I thank my parents Dr. Shree Krishan Bhargava and Kamla Bhargava for their interest at various stages of this book. Suggestions for improvement of the book from any quarter are most welcome.

June 1983 A.K. BHARGAVA

Contents

Note : Chapter and page numbers are continued from Vol. 1.

Contents of Volume 1

11 Nature of Matter and Elasticity

In the earlier chapters, we have mostly discussed the behaviour of the macroscopic objects, i.e. of those objects which can be seen by the naked eye. In fact, all the macroscopic bodies are made up of very minute particles, microscopic bodies, which cannot be seen by the naked eyes. The microscopic bodies are few in number. The three states of matter (solid, liquid and gas) and change of state can be understood in terms of these microscopic bodies and forces between them. The change of shape of a solid when an external force acts on it, is also a consequence of the internal structure of the macroscopic body.

To understand the behaviour of the objects which can be observed, it is essential to understand the internal structure of the objects. This study involves many new concepts.

11.1 BASIC CONCEPTS

D. 11.1 Matter Anything which occupies space and has mass.

NOTE Matter is a special form of energy which has mass and occupies space. The matter of mass m, has energy, E, given by the famous Einstein equation, $E = mc^2$, where c is the velocity of light in vacuum.

D. 11.2 Electron A microscopic particle having a mass 9.109×10^{-31} kg and negative electric charge of magnitude 1.602×10^{-19} coulombs. The radius of the electron is 2.817×10^{-15} m.

NOTE It is the smallest massive particle found in nature.

D. 11.3 Proton A microscopic particle having a mass 1.6725×10^{-27} kg ($\sim$ 1836 times the electron mass) and positive electric charge of magnitude 1.602×10^{-19} coulombs (equal to magnitude of the electron charge). Its radius is 1.5×10^{-14} m.

D. 11.4 Neutron A microscopic particle having zero electric charge and a mass 1.6749×10^{-27} kg (approximately equal to the proton mass). Its radius is 1.5×10^{-14} m.

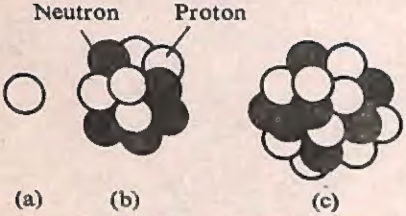


FIG. 11.1 A nucleus is a microscopic body made of protons and neutrons.

D. 11.5 Nucleus A microscopic body made up of protons and neutrons. A nucleus may have no neutrons (e.g. hydrogen nucleus has only one proton) but it cannot be without protons.

NOTES (*i*) The radius of the nucleus is given by $r = 1.5 \times 10^{-15} A^{1/3}$ m, where A is the total number of protons and neutrons in the nucleus (mass number, see D. 11.7).

(*ii*) The neutrons and the protons are restricted within a roughly spherical volume because of the existence of the strong attractive forces between a pair of two protons or two neutrons or one proton and one neutron. This attractive force between two protons is much more powerful than the repulsive electric force between them.

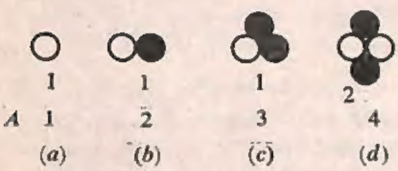


FIG. 11.2 Mass number of a nucleus is the total number of protons and neutrons in the nucleus.

D. 11.6 Atomic Number A measure of the positive electric charge of the nucleus.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION Z

SPECIFICATION The number of protons in the nucleus.

D. 11.7 Mass Number A measure of total number of protons and neutrons in the nucleus.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION A

SPECIFICATION The total number of protons and neutrons in the nucleus.

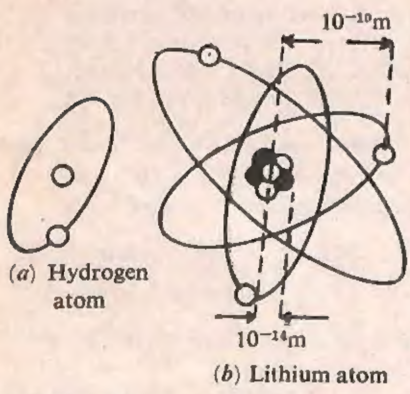


FIG. 11.3 A model of the atom. An atom is made up of a nucleus and electrons. The electrons revolve round the nucleus in fixed orbits. The number of electrons in an atom are equal to the number of protons in the nucleus.

D. 11.8 Atom A microscopic body of zero electric charge, made-up of a nucleus and electrons. The number of electrons is equal to the number of protons in the nucleus. The electrons revolve around the nucleus in fixed orbits (somewhat similar to our solar system where planets revolve around the sun in fixed orbits). The effective radius of an atom is about 10^{-10} m. The electrons are far away from the nucleus as the radius of the nucleus is about 10^{-14} m to 10^{-15} m. Nothing exists between the nucleus and the electrons.

NOTE The electrons revolve around the nucleus because of the attractive electromagnetic force between the positively charged nucleus and the negatively charged electrons.

D. 11.9 Element A macroscopic body (substance) consisting entirely of atoms having same atomic number.

NOTE In nature, 92 elements occur naturally which are arranged in the periodic table in increasing order of atomic number (hydrogen with $Z = 1$ and uranium with $Z = 92$). The addition or removal of one proton completely changes the characteristics of the element. Scientists are able to make elements upto atomic number 105 artificially.

D. 11.10 Molecule The smallest portion of a substance capable of existing independently and yet retaining the properties of the original substance.

NOTES (*i*) A molecule is formed by the combination of similar atoms or atoms of different kinds. For example, hydrogen gas is made up of molecules formed by the combination of two hydrogen atoms (H_2), whereas water has molecules formed by the combination of two hydrogen atoms and one oxygen atom (H_2O).

(*ii*) The existence of the molecule is possible because of the electromagnetic force between atoms.

(*iii*) The strength of the force between atoms varies from molecule to molecule.

(*iv*) The distance between the nuclei of any two atoms forming the molecule, known as interatomic distance, is about 10^{-10} m. If the interatomic distance decreases then the two nuclei repel each other and if it increases the two nuclei attract each other despite the two nuclei being positively charged.

(*v*) In nature, the gaseous elements (hydrogen, nitrogen, oxygen, chlorine, fluorine) except the rare gases (helium, neon, argon, krypton, xenon and radon) exist as molecules.

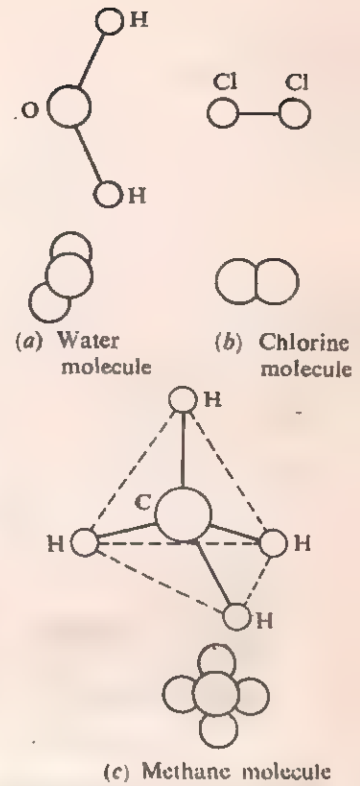


Fig. 11.4 A molecule is formed by the combination of two similar atoms or dissimilar atoms. (a) Water molecule is formed by the combination of two hydrogen and one oxygen atom. (b) Chlorine gas occurs as molecules formed by two chlorine atoms (c) Methane molecule. Carbon atom is at the centre of a tetragon and hydrogen atoms occupy corners of the tetragon.

D. 11.11 Compound A macroscopic body made up of molecules formed by the combination of two or more different atoms.

EXAMPLE Water (H_2O) is a compound, whereas oxygen gas (O_2) is not a compound.

11.2 STATES OF MATTER

D. 11.12 Force of Cohesion The force of attraction between two like molecules (or, between molecules of the same substance).

D. 11.13 Force of Adhesion The force of attraction between two unlike molecules (or, between molecules of two different substance).

NOTES (*i*) The force of cohesion and the force of adhesion arise due to the electromagnetic forces between molecules.

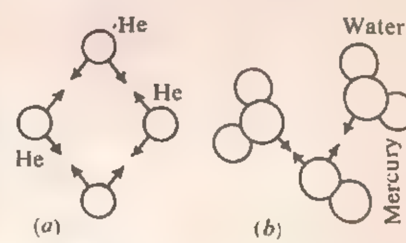
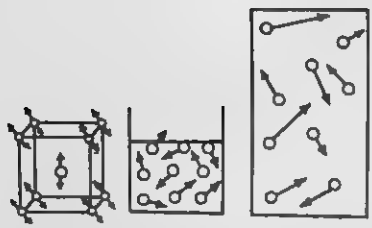


FIG. 11.5 (*a*) The force of cohesion is the force of attraction between two molecules of the same kind. (*b*) The force of adhesion is the force of attraction between two molecules of a different kind.

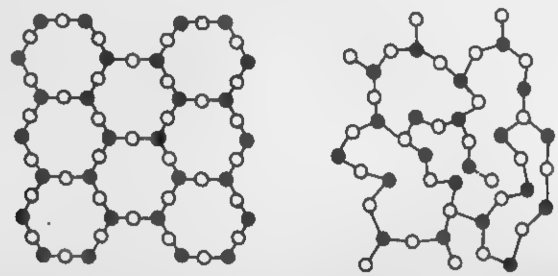
(*ii*) Sometimes the force of cohesion is more powerful than the force of adhesion and sometimes it is the other way round. For example, when a glass plate is dipped into water and taken out, some water molecules remain stuck to the glass plate; this happens because the force of adhesion between the glass and the water molecules is more powerful than the force of cohesion between the water molecules.

When a glass plate is dipped into mercury and taken out, no mercury molecule remains stuck to the glass plate; this is so because the force of cohesion between mercury molecules is more powerful than the force of adhesion between mercury and glass molecules.



(*a*) Solid (*b*) Liquid (*c*) Gas

FIG. 11.6 Three states of matter. (*a*) Solid. In this state of matter the molecules or atoms are more or less fixed and vibrate about their equilibrium positions. (*b*) Liquids. The molecules are free to move throughout the volume of the liquid but are not allowed to leave the surface because of the strong cohesive force on each other. (*c*) Gas. The cohesive force between the molecules are absent and molecules are free to move throughout the volume of the container.



(*a*) Crystalline solid (*b*) Amorphous solid

FIG. 11.7 (a) In a crystalline solid the atoms are arranged in a regular pattern. The whole solid is obtained simply by repeating this pattern. (b) In an amorphous solid the atoms are not arranged in a regular pattern. These are arranged in a haphazard manner.

D. 11.14 Solid A piece of matter which has a definite shape and size.

TYPE OF SOLIDS (*i*) *Crystalline solids* A solid in which the atoms of a molecule are arranged in a regular geometrical pattern (Fig. 11.7(*a*)).

EXAMPLES Diamond, sodium, chloride, copper, etc.

(*ii*) *Amorphous solids* A solid in which atoms are not arranged in a regular geometrical pattern (Fig. 11.7 (*b*)).

EXAMPLES Powdered carbon, plastic, glass, etc.

NOTE Every atom in a solid always vibrates about a fixed position, known as the equilibrium position (see Fig. 11.6 (*a*)). However because of simplicity, we do not put arrows in the diagram.

D. 11.15 Lattice The geometrical pattern in which the atoms of a solid are arranged (see Fig. 11.8).

NOTE Only fourteen lattice structures are possible.

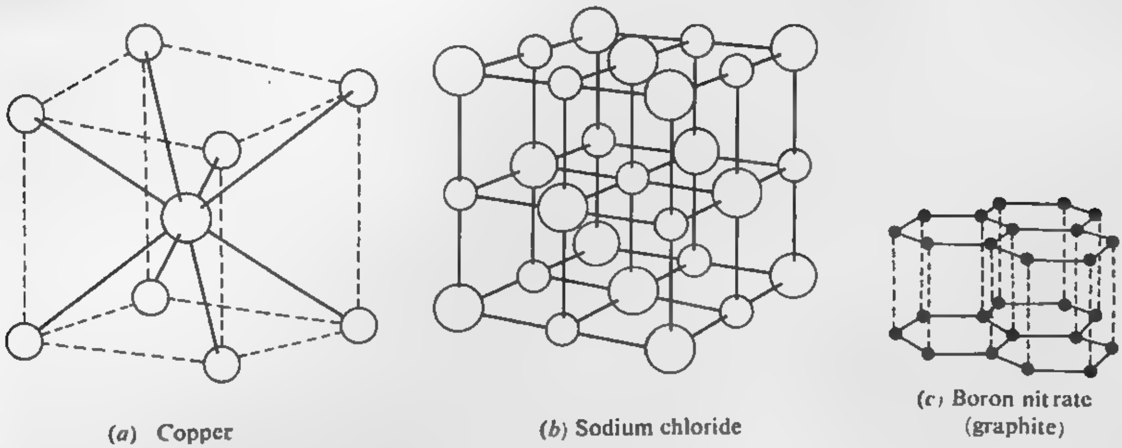


FIG. 11.8 Three dimensional crystal lattice for some of the crystalline solids.

D. 11.16 Liquid A state of matter in which the atoms or molecules are relatively free to move with respect to each other but the cohesive forces are still strong to the extent that a fixed volume is maintained.

NOTE In liquids, atoms or molecules are in continuous motion, moving in almost all directions. They do not vibrate about a fixed point.

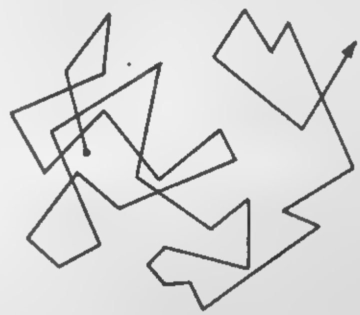


FIG. 11.9 Zig-zag motion.

D. 11.17 Random Motion A zig-zag motion of a body (see Fig. 11.9).

D. 11.18 Brownian Motion The random motion performed by particles in another medium, e.g. particles in suspension in liquid (pollen grains in water or smoke particles in air).

A particle performs random motion because it is constantly bombarded by molecules of the surrounding medium. Due to this bombardment, there is a net force acting on the particle and, hence, it moves in a straight line. After a short while the direction, as well as the magnitude of the force changes, because it is now bombarded by another set of molecules. The particle travels along some other straight line. The change of the force takes place very rapidly and consequently the particle performs random motion.

NOTES (i) This phenomenon was first noticed by a botanist Robert Brown in 1827, and was explained by Albert Einstein in 1905.

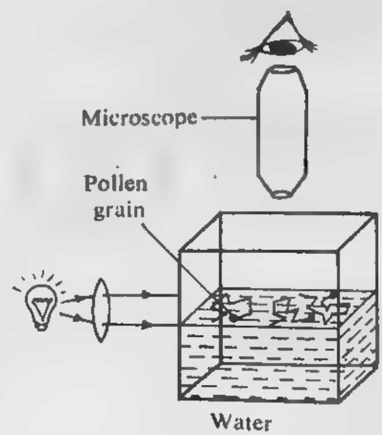


FIG. 11.10 Experimental set up to observe the Brownian motion.

(*ii*) The size of the particles must be very small otherwise the motion of the particles cannot be detected.

(*iii*) Brownian motion demonstrated that the medium is made up of very small particles which are in constant motion.

D.11.19 Gas A state of matter in which molecules are very far apart such that no cohesive force exists between them, except at the time of collision.

NOTE Since there is no cohesive force between molecules of the gas, these move freely all over the available space. Therefore, gases do not have a volume of their own. They assume the volume of the container.

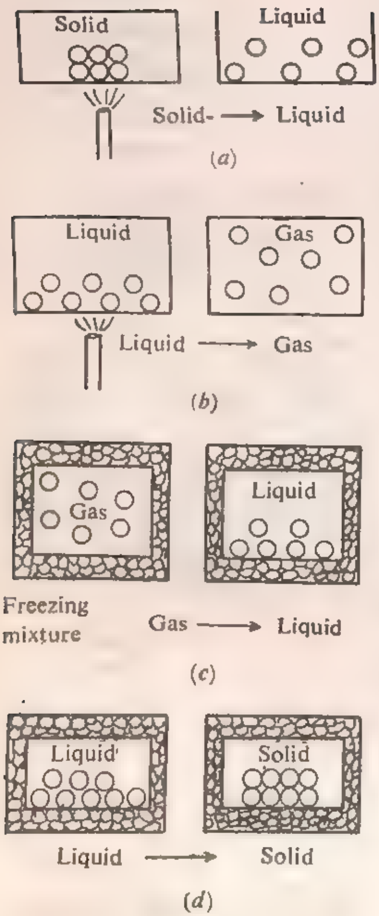


FIG. 11.11 Change of state.

CHANGE OF STATE

(*i*) *Solid to Liquid* When a solid is heated, the supplied heat energy increases the kinetic energy of the atoms. In turn, the amplitude of vibration of the atoms increases and the powerful force between the atoms of the solid becomes somewhat weaker. Hence, as the temperature of the solid increases the magnitude of the force between atoms keeps on decreasing. At a certain temperature, called the melting point, the amplitude of vibration becomes so large that the force between two atoms is no longer powerful enough to keep them vibrating about a fixed point. The atoms instead of executing oscillatory motion, are now in random motion. The cohesive force is not altogether absent but is powerful enough to keep the atoms moving only in a certain region of space and prevent molecules escaping from the free boundary of the region, This is the liquid state. The region of the space is the volume of the liquid and the free boundary of the region is the surface of the liquid.

(*ii*) *Liquid to Gas* When the temperature of the liquid is increased, the cohesive force between the liquid molecules decreases because the kinetic energy of the molecules increases and the average distance between two molecules increases. At a certain temperature, called the boiling point, most of the molecules are at very large distances (compared to the size of the molecules) from each other. At such large distances the cohesive force between two molecules is zero, and, hence, the motion of one molecule is not influenced by that of another molecule. The molecules are free to move throughout the available space, i.e. these move throughout the volume of the container. This is the gaseous state of matter.

(*iii*) *Gas to Liquid* When the temperature of the gas is decreased, the kinetic energy of the gas molecules as well as the average distance between them decreases. Because of the decrease in the distance between them, the molecules now exert a cohe-

sive force on each other. At certain temperature, the cohesive force becomes powerful enough to influence the motion of the molecules. Now the molecules are allowed to move only in a part of the volume of the container. This is the liquid state of matter.

(*iv*) *Liquid to Solid* The lowering of the liquid temperature decreases the kinetic energy of the liquid molecules. The reduction in the kinetic energy forces molecules to come nearer to each other. A molecule starts experiencing a strong cohesive force. This force increases with decreasing distance between the molecules. At a certain temperature, the cohesive forces exerted by the neighbouring molecules become so large that a molecule is no longer allowed to perform a zig-zag motion. Instead, every molecule oscillates about some mean position. In the case of crystalline solids, the mean positions are arranged in a regular lattice pattern.

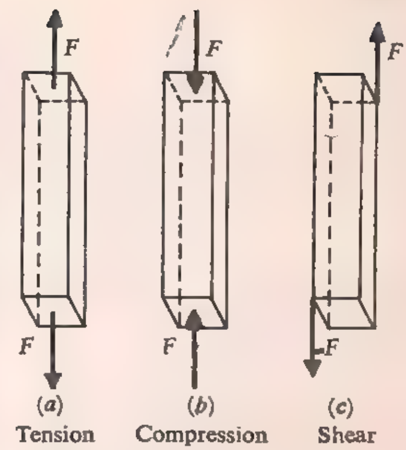


FIG. 11.12 Deforming force. (*a*) Tension:two antiparallel forces having the same line of action and the arrows directed from each other. (*b*) Compression:two antiparallel forces having the same line of action but the arrows pointing towards each other. (*c*) Shear two antiparallel forces having a different line of action.

11.3 ELASTICITY OF SOLIDS

The study of the elasticity of solids is a part of the general discipline called the mechanics of materials. This discipline is of great importance in all branches of engineering, industry and applied physical science. Most of the basic concepts are easy to understand.

To understand the concepts of elasticity, we assume that the atoms are fixed (or do not vibrate), and are bound to each other by springs (spring represents force between two atoms). The length of the spring is equal to the interatomic distance.

D.11.20 Deforming Force A force which acts on a solid body and tends to change its size and shape.

EXAMPLES See Fig. 11.12.

TYPE OF QUANTITY Vector; but here taken to be scalar.

WRITTEN REPRESENTATION F

SPECIFICATION *Magnitude*: Measured in newton along a specified direction, e.g. length of a wire.

D. 11.21 Restoring Force A force arising within a solid, due to the properties of its constituent material, which opposes the deforming forces acting on the body.

NOTES (*i*) When a solid is subjected to an external force, say a compressional force, the interatomic distance decreases. The decrease in the interatomic distance produces a repulsive force which tries to repel the atoms to their zero external force position. Similarly, when an extensional force is applied, the increase in the interatomic distance produces an attractive force

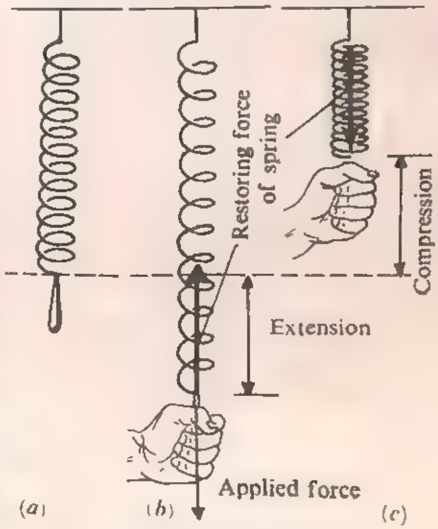


FIG. 11.13 Restoring force in a spring. This is a force acting in a body which tries to bring back the deformed body to its original shape. It is equal in magnitude to the applied force but oppositely directed. It is always opposite in direction to the elastic deformation

between atoms. This attractive force tries to bring back the atoms to their original positions. These repulsive and attractive forces produced inside the solid because of an external applied force, are collectively known as the restoring force. In the equilibrium state, the restoring force is equal in magnitude but opposite in direction to the applied force.

(*ii*) The restoring force is a reaction to the applied deforming force and obeys Newton's third law of motion (Chapter 3, Law 4).

D. 11.22 Perfectly Rigid Body A solid body in which the distance between every pair of its constituent particles remains constant under the action of any deforming force.

LIMITATIONS OF THE CONCEPT This concept is an ideal. In all real bodies, the distance between constituent particles changes under the application of suitable deforming forces.

D. 11.23 Elasticity The property of a body or a material by virtue of which it *regains* its original shape and size when the external deforming forces are removed from it.

D. 11.24 Perfectly Elastic Body A solid body in which the internal restoring force completely removes the effect of a deforming force, so that the body *regains* its original size and shape after the removal of the deforming force.

LIMITATIONS OF THE CONCEPT (*i*) This is an ideal. No real body can completely regain its original shape and size and internal arrangement of particles after being subjected to deformation.

(*ii*) In practice, an 'elastic body' regains its original shape and size to a sufficient extent for the concept of elasticity to be useful.

NOTE A quartz fibre is the solid body closest in practice to the above concept of a perfectly elastic body.

D. 11.25 Plasticity The property of a body or a material by virtue of which it *does not regain* its original shape and size when the external deforming forces are removed from it.

D. 11.26 Perfectly Plastic Body A solid body in which the internal restoring force is completely absent, so that the body *retains* its deformed shape and size after the applied deforming force has been removed.

LIMITATIONS OF THE CONCEPT (*i*) This is an ideal. Every real body has some (non-zero) restoring force present in it, which removes at least a part of the effect of a deforming force.

(*ii*) In practice, a 'plastic body' retains a deformation to a sufficient extent for the concept of plasticity to be useful.

NOTE Mud and putty are materials which in practice are closest to the above ideal of perfectly pl astic behaviour.

11.4 STRESS AND STRAIN IN ELASTIC BODIES

The measurement and analysis of the properties of elastic bodies is done in terms of two essential quantities: strain and stress. These are related to the concepts of Section 11.3, and enable us to understand them.

D. 11.27 Strain A measure of the change in the shape and/or size of a solid body caused by a deforming force.

EXAMPLES See Fig. 11.14.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION Strain

SPECIFICATION The change in length per unit length (*longitudinal strain*) or the change in volume per unit volume (*bulk strain*) or the angular deformation at constant volume (*shear strain*).

NOTES (*i*) For each type of strain, the mathematical expression is different.

(*ii*) Longitudinal and bulk strain have no units; shear strain is measured in radian (rad).

(*iii*) Here we shall deal with only longitudinal strain (see D. 11.28 below).

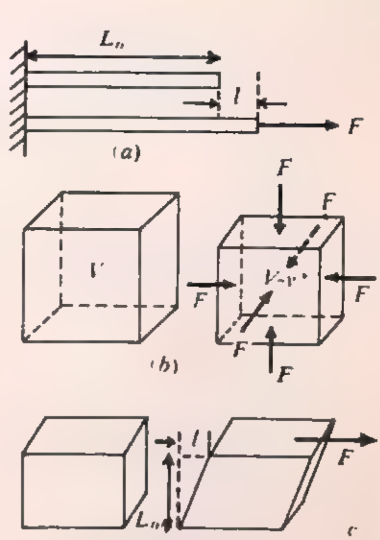


FIG. 11.14 Three kinds of strain. (*a*) (*b*) Longitudinal strain, l/L_0. We take it to be always positive. (*c*) Volumetric strain, $-v/V$ when volume decreases, and v/V when volume increases. Forces are applied in such a way that there is no change in the shape of the body. (*d*) Shear strain, l/L_0. Here the force changes the shape of the body without changing its volume.

D. 11.28 Longitudinal Strain A measure of the change in the length of a body caused by a deforming force.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION Strain

SPECIFICATION *Magnitude*: The change in length per unit length of the body. No units.

MATHEMATICAL EXPRESSION The ratio of the change in length to the original length of the body;

$$\text{Longitudinal strain} = \frac{\text{change in length}}{\text{original length}}, \text{ or}$$

$$\text{Strain} = \frac{l}{L_0} \qquad (E.\ 11.1)$$

$l = L - L_0$ for tension, $l = L_0 - L$ for compression.

NOTES (*i*) According to E. 11.1, strain is always positive.

(*ii*) In terms of the structure of solids the change of the spring length along the direction of the applied force divided by the initial spring length is the longitudinal strain.

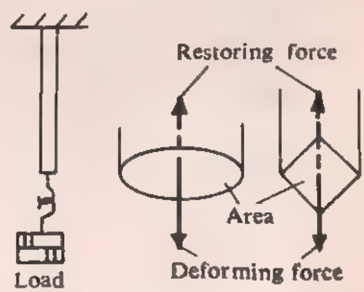


FIG. 11.15 Stress is equal to the restoring force, per unit area. But since the restoring force is equal to the deforming force, stress is deforming force per unit area.

D. 11.29 Stress A measure of the internal restoring force which opposes the external applied force and tries to bring the body back to its original shape and size.

EXAMPLE See Fig. 11.15.

TYPE OF QUANTITY Here considered as scalar.

WRITTEN REPRESENTATION Stress.

SPECIFICATION Measured as the deforming force per unit area. The 'area' to be specified depends upon the way the deforming force is applied and the kind of strain produced. Always measured in newton per square metre (N m^{-2}).

NOTE For our purpose, the stress is equal to the applied deforming force per unit area. In practice, for some kinds of crystals the stress cannot be calculated as deforming force per unit area.

D. 11.30 Tensional Stress A measure of the restoring force producing a longitudinal strain in a body.

TYPES OF QUANTITY Here considered as scalar.

WRITTEN REPRESENTATION Stress.

SPECIFICATION: *Magnitude*: Measured as the deforming force per unit area of cross-section of the body (Fig. 11.15) (See Note D. 11.29). Measured in Newton per square metre (N m^{-2}).

MATHEMATICAL EXPRESSION

$$\text{Tensional stress} = \text{restoring force per unit area} = \frac{\text{deforming force}}{\text{area of cross-section}}$$

$$\text{Stress} = \frac{F}{A} \qquad (E.\ 11.2)$$

TABLE 11.1 The elastic limit for some solid substances.

Material	*Elastic limit* ($\times 10^8$ N m^{-2})
Aluminium	1.3
Brass	3.8
Copper	1.5
Iron	1.6
Steel	4.1

TABLE 11.2 The Young's modulus for some solid bodies.

Material	*Y* ($\times 10^{10}$ N m^{-2})
Aluminium	7.0
Bone	1.3 to 2.5
Brass	9.0
Copper	11.0
Glass	5.5
Hair	0.2
Iron	9.0
Lead	1.6
Nickel	21.0
Rubber	0.0004
Steel	21.0

D. 11.31 Elastic Limit A magnitude of the stress characteristic of a material, such that when a stress of greater magnitude is applied to a body of the material, the body cannot regain its original shape and/or size.

EXAMPLES See Table 11.1.

LIMITATIONS OF THE CONCEPT (*i*) The elastic limit in practice is not a precise magnitude; usually, it is a range of values of stress.

(*ii*) The elastic limit is a characteristic of a particular material e.g. copper, iron, steel; all bodies made of a particular material have the same elastic limit.

(*iii*) For each material, the elastic limit has to be determined experimentally.

LAW 12 : HOOKE'S LAW

If the stress applied on a solid body is less than the elastic limit of the material of the body, the magnitude of the stress is

directly proportional to the strain produced by it.

or

Within elastic limit stress is directly proportional to the strain.

MATHEMATICAL EXPRESSION

$$\text{Stress} \propto \text{strain, or}$$

$$\text{Stress} = \text{constant} \times \text{strain} \qquad (E.\ 11.3)$$

LIMITATIONS OF THE LAW Hooke's law is valid only when the strain is independent of time; i.e. when the strain does not change during the time of application of the deforming force.

D. 11.32 Modulus of Elasticity The ratio of stress to strain for a solid body obeying Hooke's law.

NOTES (*i*) The modulus of elasticity is a characteristic of the material of the body.

(*ii*) There are several moduli of elasticity for each material corresponding to various types of strain, e.g. *Young's modulus* corresponds to longitudinal strain; *bulk modulus* corresponds to bulk strain; *shear modulus* corresponds to shear strain (see D.11.27).

(*iii*) For longitudinal strain and tensional stress, a body obeying Hooke's Law, obeys E.11.3.

$$\text{Stress} = \text{constant} \times \text{strain}$$

The constant of proportionality is called Young's modulus, which has the symbol Y.

$$Y = \frac{\text{stress}}{\text{strain}} \qquad (E.\ 11.4)$$

It is measured in newton per metre square (N m^{-2}).

DETERMINATION Young's modulus can be determined in the laboratory using the apparatus shown in Fig. 11.16.

The material is taken in the form of a solid wire. The experimental wire is subjected to a tensional stress by elongating it with the help of a variable load M. For each value of M (which acts on the area of cross-section of the experimental wire), the elongation produced is measured by comparison with the reference wire.

From the observations stress and strain are calculated. The stress is plotted against the strain on graph paper (Fig. 11.17).

If the stress has been less than the elastic limit of the experimental wire, and the wire obeys Hooke's law, the graph is a straight line (Fig. 11.17). The *slope* of the line is the ratio of stress to strain and, hence, E. 11.4 gives the value of Young's modulus for the material of the wire.

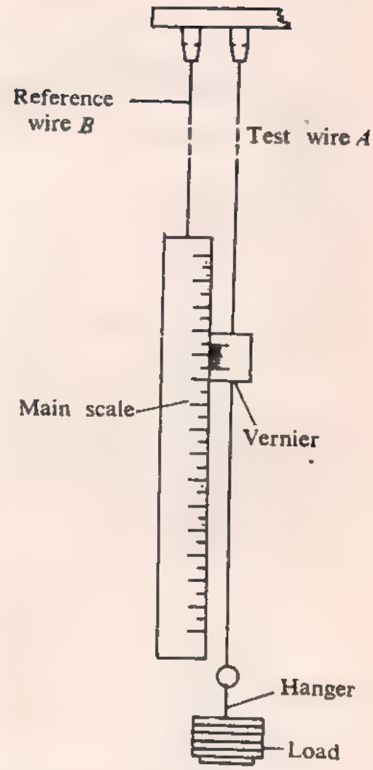


FIG. 11.16 Determination of Young's Modulus. The apparatus consists of two wires A and B made from the same material. The wires are suspended vertically from a fixed support. The reference wire A has the main scale and wire B carries a vernier and a hanger. Initially, a large weight is suspended on the hanger to remove any kink in the test wire B. The heavy load is removed and then the weights in constant multiple, say 0.5kg, are added at a time to the hanger. The readings of the scale are noted which gives the change of length of wire B. The diameter and the length of the wire B is also measured. A graph is plotted between load and the reading of the scale.

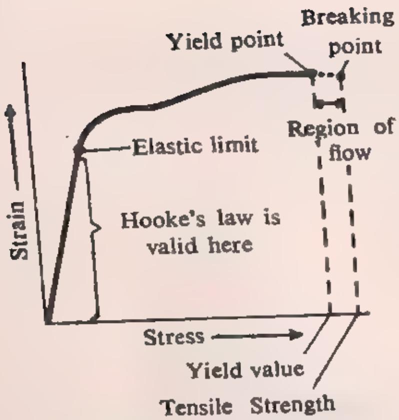


FIG. 11.17 Stress-strain graph for an elastic wire. The point on the graph beyond which the graph is not a straight line is known as the elastic limit.

11.5 SOME PROPERTIES OF ELASTIC BODIES

Besides the properties described above, several other concepts are necessary to understand the behaviour of elastic bodies.

D. 11.33 Limit of Proportionality The point on the stress-strain graph for an elastic material at which the graph begins to curve. (The limit of proportionality roughly corresponds to the elastic limit of the material.)

NOTE The stress-strain relationship beyond the limit of proportionality does not obey Hooke's law (E. 11.3 and E. 11.4).

D. 11.34 Flow A material is said to flow when the stress applied to it is so great that, on its removal the body continues to be deformed under its own weight.

NOTE See Fig. 11.17 for the 'region of flow' on the stress-strain graph. The graph is curved as shown because the stress-strain relationship within the material changes as the material flows. Also see D. 11.35 below.

D. 11.35 Yield-point The value of the stress-strain ratio at which the material begins to flow.

NOTES (*i*) See Fig. 11.17 for the position of the yield-point on the stress-strain graph.

(*ii*) When the stress-strain ratio increases beyond the yield-point value, the material flows at room-temperature, somewhat in the manner it flows in the molten state at high temperatures.

(*iii*) See D. 11.36, D. 11.37 and D. 11.38.

D. 11.36 Yield-value The value of the applied stress corresponding to the yield-point of the material.

NOTE See Fig. 11.17 and D. 11.35.

D. 11.37 Ductility The property of a material, by virtue of its elasticity, because of which the material can be drawn into wires.

NOTES (*i*) A material becomes ductile when it is deformed beyond its yield point (see D. 11.35 and D. 11.36 above), and begins to flow.

(*ii*) Wires are made from ductile materials by 'drawing out' the flowing material into long thin cylindrical forms. Wires are *not* made from a material in the molten state.

D. 11.38 Malleability The property of a material, by virtue of its elasticity, because of which the material can be made into sheets.

NOTES (*i*) A material becomes malleable when it is in the 'region of flow' (see D. 11.34 to D. 11.36 above).

(*ii*) Sheets of elastic material are made by 'beating' or pressing the flowing material into thin flat forms. They are *not* made from a material in the molten state.

D. 11.39 Breaking-Point The value of the stress-strain ratio, for a flowing material, at which the body begins to break up.

NOTES (*i*) The breaking-point is the last value on the stress-strain graph (see Fig. 11.17).

D. 11.40 Tensile Strength The value of stress required to break a material under tension.

EXAMPLES See Table 11.3.

D. 11.41 Compressive Strength The value of stress required to break a material under compression.

EXAMPLES See Table 11.3.

(*ii*) The brittleness (see D. 11.42) of a material depends upon its breaking-point.

D. 11.42 Brittleness The property of a material because of which a body breaks up under stress.

NOTES (*i*) The breaking-point value of the stress-strain ratio marks the beginning of the condition of brittleness of a material.

(*ii*) A brittle material has a small region of flow and a low limit of proportionality.

D. 11.43 Creep The slow permanent deformation of a body under the sustained application of stress.

NOTES (*i*) In the condition of creep, the strain of the body changes with time.

(*ii*) In this condition, the body does not obey Hooke's law.

TABLE 11.3 The tensile and compressive strength for some materials

Material	*Tensile strength* ($\times 10^8$ Nm^{-2})	*Compressive strength* ($\times 10^8$ Nm^{-2})
Aluminium	1.4	
Bone		
compact	1.21	1.67
spongy	0.012	0.019
Brass	4.5	
Copper	3.4	
Glass	0.5	11
Hair	1.96	
Steel	5	
Wood	0.2-1.1	1

SOLVED EXAMPLES

EXAMPLE 11.1 When a 40.0 cm long wire is subjected to an external force, its length becomes 40.2 m. Determine the strain in the wire.

Solution $L_0 = 40.0$ cm $= 0.400$ m, $L = 40.2$ cm $= 0.402$ m, and $l = L - L_0 = 0.402$ m $-$ 0.400 m $= 0.002$ m

$$\text{Strain} = \frac{l}{L_0} = \frac{0.002 \text{ m}}{0.400 \text{ m}} = 0.005$$

Answer The strain in the wire is 0.005.

EXAMPLE 11.2 What is the stress, if the restoring force in a wire is 50 N ? The area of cross-section of the wire is 0.0005 m^2.

Solution According to the definition, stress = the restoring force per unit area

$$= \frac{50 \text{ N}}{0.0005 \text{ m}^2} = 10^5 \text{ N m}^{-2}$$

Answer The stress in the wire is 10^5 N m^{-2}.

EXAMPLE 11.3 A force of 53.9 N is applied along the length of a wire of radius 0.70 mm. Calculate the stress.

Solution $r = 0.70$ mm $= 7.0 \times 10^{-4}$ m, and $F = 53.9$ N

$$A = \text{area of cross section} = \pi r^2$$
$$= \frac{22}{7} \times (7.0 \times 10^{-4} \text{ m})^2$$
$$= 1.54 \times 10^{-6} \text{ m}^2$$
$$\text{Stress} = \frac{F}{A} = \frac{53.9 \text{ N}}{1.54 \times 10^{-6} \text{ m}^2}$$
$$= 3.5 \times 10^7 \text{ N m}^{-2}$$

Answer The stress in the wire is 3.5×10^7 N m^{-2}.

EXAMPLE 11.4 The elastic properties of materials are of considerable importance in deciding the safety factors in such things as the construction of bridges and tall buildings, installation of elevators, etc. An elevator is a device which carries human beings or luggage from one storey of a building to another storey. It is essentially a large box of mass about 350 kg suspended from a cylindrical wire of steel with an area of cross-section 10^{-4} m^2. The maximum permissible limit of stress in steel is 1.225×10^8 N m^{-2}. Determine how many persons it can carry safely, if the average mass of a person is 60 kg.

Solution Maximum stress $= 1.225 \times 10^8$ N m^{-2}, $A = 10^{-4}$ m^2 and mass of one passenger $\doteq 60$ kg.

Maximum force $= F = A \times$ maximum stress

$$= 10^{-4} \text{ m}^2 \times 1.225 \times 10^8 \text{ N m}^{-2}$$
$$= 1.225 \times 10^4 \text{ N.}$$

F = force on the wire = total weight of the elevator

= weight of the box + total weight of persons in the elevator

$= (350 + 60n)$ kg $\times 9.8$ m s^{-2}

n = number of persons in the elevator

$(350 + 60n) \times 9.8$ N $= 1.225 \times 10^4$ N, or

$350 + 60n = 1250$

$60n = 900$, or $n = 15$

Answer The elevator can carry 15 persons safely.

EXAMPLE 11.5 In a certain pump a cylindrical steel rod, of length 0.200 m and area of cross-section 10^{-4} m^2, is used as a piston. When the rod is completely pushed into the cylinder, its length is found to be 0.199 m. The compressional longitudinal force on the rod is 10^5N. Calculate (*i*) the strain, (*ii*) the stress, and (*iii*) Young's modulus for steel.

Solution $L_0 = 0.200$ m, $L = 0.199$ m, $A = 0.0001$ m^2, and $F = 10^5$ N

(*i*) $l = L_0 - L = 0.200 \text{ m} - 0.199 \text{ m}$
$= 0.001$ m

$$\text{Strain} = \frac{l}{L_0} = \frac{0.001 \text{ m}}{0.200 \text{ m}} = 0.005$$

(*ii*) $$\text{Stress} = \frac{F}{A} = \frac{10^5 \text{ N}}{0.0001 \text{ m}^2} = 10^9 \text{ N m}^{-2}$$

$$Y = \frac{\text{Stress}}{\text{Strain}} = \frac{10^9 \text{ N m}^{-2}}{0.005}$$
$$= 20 \times 10^{10} \text{ N m}^{-2}$$

Answer The strain and stress on the steel rod are 0.005, and 10^9Nm^{-2}, respectively. The Young's modulus for steel is 20×10^{10} N m^{-2}.

NOTE Remember that the strain for a compressional force is equal to (unstretched length − stretched length).

EXAMPLE 11.6 We have seen that when a person stands on the toes of one foot, the force

on the ankle-joint is 228 kg-wt (Example 7.9). This is equal to a compressional force of 228 kg-wt acting on the bone joining the ankle and the knee. The effective area of cross-section of the bone can be taken to be 3.8×10^{-4} m^2 and the length of the bone to be 40.0 cm. Y for bone can be taken to be 2.0×10^{10} N m^{-2}. Determine (*i*) the stress, and (*ii*) the change in the length of the bone.

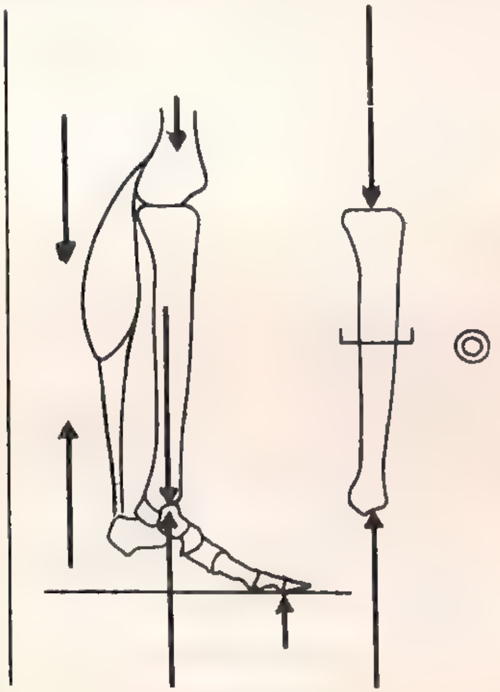


FIG. 11.18

Solution $F = 228$ kg-wt $= 228$ kg-wt$\times 9.8$ N kg-wt^{-1} $= 2234.4$ N, $A = 3.8\times10^{-4}$ m^2, $Y = 2.0\times10^{10}$ N m^{-2}, and $L_0 = 40.0$ cm $= 0.4$ m.

$$(i)\ \text{Stress} = \frac{F}{A} = \frac{2234.4\ \text{N}}{3.8\times10^{-4}\ \text{m}^2} = 5.88\times10^{6}\ \text{N m}^{-2}$$

$$(ii)\ \text{Strain} = \frac{\text{Stress}}{Y} = \frac{5.88\times10^{6}\ \text{N m}^{-2}}{2.0\times10^{10}\ \text{N m}^{-2}} = 2.94\times10^{-4}$$

$$l = L_0\times\text{Strain} = 0.4\ \text{m}\times2.94\times10^{-4} = 1.2\times10^{-4}\ \text{m} = 0.00012\ \text{m} = 0.12\ \text{mm}$$

Since the force compresses the bone, its length will decrease.

Answer The compressional stress on the bone is 5.88×10^{6} N m^{-2}. The length of the bone will decrease by 0.00012 m (0.12 mm).

EXAMPLE 11.7 In an experiment, the following data was obtained for an aluminium wire.

Mass suspended from the wire (kg)	0.50	1.00	1.50	2.00	2.50	3.00	3.50
Length of the wire (m)	2.0007	2.0014	2.0021	2.0028	2.0035	2.0040	2.0042

The starting length of the wire is 2.0000 m and its area of cross-section is 20.0×10^{-8} m^2. Plot a graph between stress and strain. From the graph calculate Young's modulus and the elastic limit for aluminium.

Solution $A = 20\times10^{-8}$ m^2. $L_0 = 2.0000$ m. Let M be the mass suspended on the wire. $F = M\times g = M\times9.8$ m s^{-2} $= 9.8\times M$m s^{-2}. Let L be the length of the wire when a mass of M is the load on the wire.

$$\text{Stress} = \frac{F}{A} = \frac{9.8\times M\text{m s}^{-2}}{20\times10^{-8}\ \text{m}^2} = 49\times10^{6}\times M\ \text{m}^{-1}\ \text{s}^{-2}$$

$$\text{Strain for a given load} = \frac{L-L_0}{L_0} = \frac{L-2.0000\ \text{m}}{2.0000\ \text{m}}$$

From these two relations we obtain the following table :

Stress (10^6 N m^{-2})	24.5	49	73.5	98	122.5	147	171.5
Strain (10^{-4})	3.5	7	10.5	14	17.5	20	21

Now take a graph paper and plot the stress on the x-axis and the strain on the y-axis. Let a stress of 24.5×10^{6} N m^{-2} be represented by 1 unit on the x-axis, and a strain of 3.5×10^{-4} be represented by 1 unit along the y-axis. Now draw a curve through the points $ABCDEFG$. The portion of the curve $ABCDE$ is a straight line. In this portion Hooke's law is obeyed.

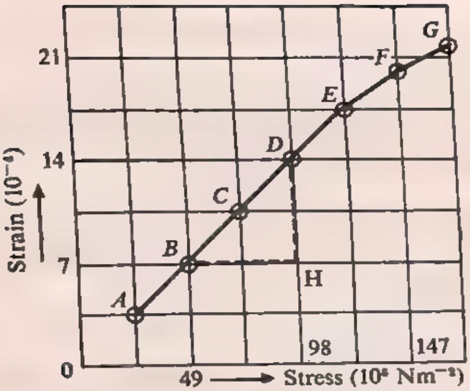


FIG. 11.19 Stress-strain graph for Example 11.7.

Choose two points B and D on the straight line portion.

$$Y = \frac{\text{stress}}{\text{strain}} = \frac{BH}{DH} = \frac{49\times10^{6}\ \text{N m}^{-2}}{7\times10^{-4}}$$
$$= 7.0\times10^{10}\ \text{N m}^{-2}$$

Elastic limit = stress corresponding to the point beyond which graph between stress and strain is no longer a straight line.

= stress corresponding to the point E
= 1.22×10^{8} N m^{-2}

Answer For aluminium, $Y=7.0\times10^{10}$ N m^{-2}, and the elastic limit is 1.22×10^{8} N m^{-2}.

PROBLEMS

11.1 An external force produces a strain of 0.004 in a 0.50 m long wire. Determine the change in the length of the wire.

11.2 A rubber band of length 60 cm is stretched by 3 cm. What is the strain ?

11.3 When a force was applied along the length of a wire, the length of the wire was found to be 0.6231 m. If the strain in the wire was 0.005, what was the length of the wire before it was stretched?

11.4 Two wires A and B are made of the same material. The wire A is twice as long as wire B. Determine the ratio of the change in length of wire A with respect to that of wire B when both of these are subjected to the same deforming force. Both wires have same area of cross-section.

11.5 What will be the restoring force in a specimen of cross-sectional area 1.0×10^{-6} m^2 subjected to a stress of 9.8×10^{8} N m^{-2} ?

11.6 Find the effective area of cross-section of a hollow cylindrical tube in which the stress is 10^{7} N m^{-2} and the restoring force is 500 N.

11.7 A steel rod is subjected to a compressional force of 100 N. What is the restoring force developed in the rod which opposes, (is a reaction to) the external force ?

11.8 On a silver wire of square cross-section (of side 1.0 mm), a mass of 9.5 kg is suspended. Calculate the stress in the wire.

11.9 What is the applied force if the stress in a bar of rectangular cross-section, of sides 0.01 m and 0.02 m, is 10^{8} N m^{-2} ?

11.10 Determine the area of cross-section of a wire if a deforming force of 60 N produces a stress of 3.0×10^{8} N m^{-2}.

11.11 An overhead water-tank, supported on six identical iron pillars of square cross-section, is designed to hold 15×10^{4} kg of water. What should be the minimum size of each pillar if the safe limit of the stress is 5.0×10^{7} N m^{-2}. The elastic limit of iron is 1.6×10^{8} N m^{-2} ?

Hint : The force on each pillar

$$= \frac{15\times10^{4}\times9.8\ \text{N}}{6}$$

11.12 How much force can be applied safely on a wire of radius 7.0 mm if the safe working stress of a brass wire is half of the elastic limit. The elastic limit of brass wire is 3.8×10^{8} N m^{-2}.

11.13 In an experiment, the following observations were taken. Does the wire obey Hooke's Law?

Load (kg)	0	1.0	1.5	2	2.5	3.0
Change in length (m)	0	0.002	0.004	0.006	0.008	0.010

(*Hint* : Draw a graph between load and change in length.)

11.14 Determine Young's modulus for glass if a stress of 1.1×10^{7} N m^{-2} produces a strain of 2.12×10^{-4} in it.

11.15 In the case of bones, Hooke's Law is valid upto the point of fracture. Suppose a 40 cm long bone of a woman's leg is subjected to a stress 17×10^7 N m^{-2} (equal to the compressional load at which fracture occurs). Determine the (*i*) strain at the point of fracture and (*ii*) the change in the length of the bone. Y of bone $= 2.2 \times 10^{10}$ N m^{-2}.

11.16 Find the force which will double the length of the wire of radius 1.20 mm if Y of the wire is 7.0×10^{10} N m^{-2}. (In actual practice, the wire will break down much before the stress required to double the length of the wire is applied. Compare your results with the breaking stress given in Table 11.3.)

11.17 A 40 g mass is suspended on a 0.100 m long hair. What will be the area of cross-section of the hair if the stretched length of hair is 0.101 m? Y of hair $= 2.0 \times 10^9$ N m^{-2}.

11.18 An 80 cm long copper wire of cross-sectional area 1.0×10^{-6} m^2, is subjected to a stretching force of 550 N. If the change in length is 4.0 mm, determine Young's modulus for copper.

11.19 When you hold an object in your hand, such that your forearm remains horizontal, a compressional force of 882 N acts on the bone of your upper arm. Determine Y for the bone from the following data: Length of the bone $= 0.30$ m. Change in the length of the bone $= 7.35 \times 10^{-6}$ m. Area of cross section of the bone $= 24 \times 10^{-4}$ m^2.

11.20 In a nuclear reactor, the element lead is used to protect persons working there from radioactive hazards. A 3 m high wall is constructed by putting thirty cubical lead bricks of side 10 cm one over the other. By how much would one side of the lower-most brick decrease, if Y of lead is 1.8×10^{10} N m^{-2}, and the mass of one brick is 11 kg?

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FIG. 12.1 In monatomic molecules internal energy is that of linear motion. In diatomic molecules the internal energy may be of linear, rotational or vibrational motion. In solids, as the atoms have fixed positions, the internal energy is in the form of vibrational motion.

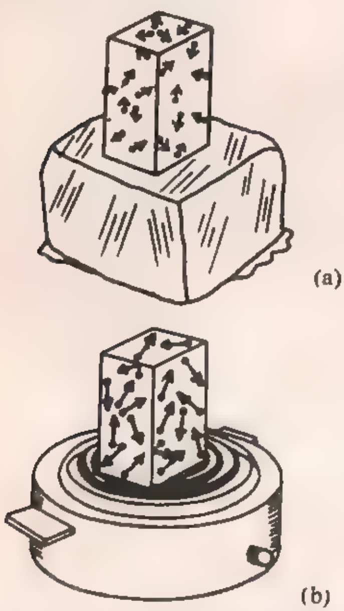


FIG. 12.2 Heat energy increases as kinetic energy of the molecules increases.

12 Temperature and Volume Change

When the brakes of a running car are applied it comes to rest. What happens to its kinetic energy? The energy seems to have disappeared. Is the law of conservation of energy violated? The concept that energy is always conserved no matter what happens cannot be maintained unless another form of energy, namely heat energy is understood and included in the discussions. Heat energy in a hot metal bar is just as real and important form of energy as the mechanical energy of a falling hammer. The mechanical energy is easy to visualise. However, heat energy is not easy to visualise because it is a manifestation of the microscopic action of atoms and molecules.

12.1 BASIC CONCEPTS

The study of heat energy and its measurement requires understanding of an entirely new set of concepts. These concepts are completely different from those discussed in earlier chapters.

D.12.1 Internal Energy The energy of an object associated with its constituents, i.e. atoms or molecules.

D.12.2 Heat energy (*or, Thermal energy, or simply, Heat*). A form of energy. It is the internal energy of an object in the form of kinetic energy of its constituent atoms or molecules.

D.12.3 Temperature A measure of the heat energy possessed by a body, or the degree of the hotness or coldness of a body expressed on some chosen scale.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION T, t, θ

SPECIFICATION A number on some chosen scale. Measured in Kelvin (K). See D.1.5 and D.12.4.

TABLE 12.1 Some sources of heat energy.

Process	*Principle*	*Uses*
Burning	The carbon and hydrogen of the fuel combine with atmospheric oxygen. The resulting chemical reactions produce the energy which is mostly in the form of heat.	In the kitchen, furnace.
Mechanical work	Part of work done is always converted into heat energy.	
Electric current	The electrons moving inside a resistor under the influence of the electric field, collide with the atoms or molecules of the conductor and transfer their kinetic energy to the molecules. The increase in kinetic energy appears as heat energy.	Electrical heating appliances.
Mass energy	In some nuclear reactions part of the mass is converted into energy. This energy in atomic power plants is withdrawn as heat energy of the working fluid.	To produce electricity in atomic power plants; enormous amount of energy in sun and stars.

NOTES (i) Temperature is a fundamental quantity. It cannot be expressed in terms of mass, length and time.

(ii) The temperature of an object is a measure of how rapidly the molecules are moving.

(iii) The temperature of an object does not give any indication of the total internal energy possessed by a body.

(iv) Temperature is a measure of only the kinetic energy of atoms or molecules.

(v) Temperature plays a more important role in the study of heat energy than any other quantity.

D.12.4 Kelvin SI base unit of temperature.

WRITTEN REPRESENTATION K

SPECIFICATION The fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

NOTE The unit of temperature is the base unit in all the systems.

12.2 MEASUREMENT OF TEMPERATURE

Our ability to measure temperature accurately plays a vital role in the study of the effect of heat energy on ourselves and our surroundings. Whether it is our health or construction of a bridge or manufacturing of drugs and other items, all these require maintenance of accurate temperatures.

D.12.5 Thermometry The science dealing with the measurement of low and moderate temperatures (roughly upto 1000 K).

TABLE 12.2 Some representative temperatures (in Kelvin) found in the universe.

Interior of hottest star	10^{10}
Centre of H-bomb explosion	10^{8}
Interior of sun	10^{7}
Surface of hottest star	5×10^{4}
Centre of earth	1.4×10^{4}
Surface of sun	7.3×10^{3}
All solids and liquids vaporize	2.7×10^{3}
Water boils	373
Human body	310
Water freezes	273
Nitrogen liquefies	77
Hydrogen liquefies	20
Helium liquefies	4.2
Lowest achieved	10^{-6}
Minimum theoretically possible (impossible to achieve practically)	0

heat energy.

FIG. 12.3 Heat energy flows from a region of higher temperature to a region of lower temperature. The direction of flow of heat energy does not depend on the amount of heat energy contained in each body. The energy continues to flow until the temperatures of both the bodies in contact become equal.

PRINCIPLE Any physical property ... with temperature is used to measure temperature [e.g. expansion of a solid, liquid or gas, change in resistance (D.18.22), etc.]. See Table 12.3.

EXAMPLES Mercury thermometer, platinum resistance thermometer, constant volume hydrogen thermometer, etc.

D.12.7 Working Substance The substance whose properties are made use of in measuring temperature.

EXAMPLES Mercury, hydrogen, platinum, etc.

TABLE 12.3 Various kinds of thermometers.

Kind of thermometer	*Property of working substance*	*Working substance*	*Range*
Liquid	Change in volume	Mercury, (alcohol)	−39°C to 357°C
Constant volume gas	Change in pressure of the gas at constant volume	Helium Hydrogen Nitrogen	−267°C to 500°C −200°C to 500°C upto 1500°C
Resistance	Change in resistance	Platinum	−200°C to 1200°C
Thermocouples	Variations of EMF* at the junction of two different metals	Silver-constantan, Copper-iron	

*EMF stands for electromotive force (D.18.19).

D.12.8 Liquid Thermometer A kind of thermometer in which the expansion or contraction of a liquid with change in temperature forms the basis of measurement of temperature.

EXAMPLES Mercury and alcohol thermometers.

PROPERTIES OF A SUITABLE THERMOMETER LIQUID (i) It should not wet the sides of the glass container.

(ii) It should be easily available in pure form.

(iii) Its expansion should be uniform throughout the range of measurement, otherwise the degree markings will not be of equal size.

(iv) The expansion should be large so that the degree markings are reasonably apart.

(v) It should be easily distinguishable from the glass container.

(vi) It should be a good conductor of heat so that it can quickly attain the temperature of the body.

alcohol satisfies only (ii), (iii), (iv) and (vii). In properties (i), (vi) and (viii) alcohol is inferior to mercury while in property (iv) it is better. Water, except for property (ii), is inferior to both mercury and alcohol in all other respects.

NOTE Mercury is used for most scientific work, and alcohol in places where accuracy is not essential.

D.12.9 Ice Point—Lower Fixed Point The temperature corresponding to the melting point of pure ice.

NOTE Solid ice is not used because its temperature may be less than the lower fixed point.

D.12.10 Steam Point—Upper Fixed Point The temperature of steam from boiling water at 1 atmospheric pressure (101 325 N m^{-2}).

NOTE In places where pressure is not 1 atmosphere, one must find the correct steam point at the given pressure from the standard tables.

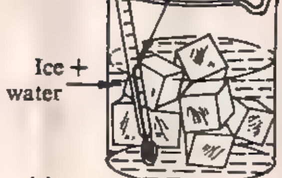
D.12.11 Fundamental Interval The temperature difference between lower fixed point and upper fixed point on a given temperature scale (D.12.13). See Table 12.4.

D.12.12 Unit of Temperature Scale The value of one subdivision of the fundamental interval. See Table 12.4.

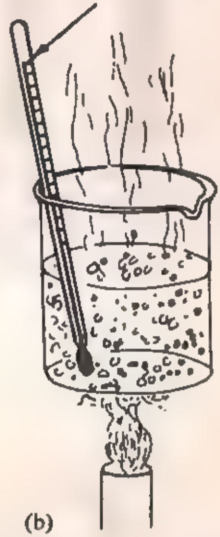
D.12.13 Thermometric Scales A scale on which the temperature of the body is expressed. See Table 12.4.

NOTES (i) The Celsius scale was introduced by Anders Celsius (1701-44). Formerly degree Celsius was known as degree Centigrade. However in 1949 it was changed through an international agreement. It is the most widely used scale.

(ii) The Fahrenheit scale was devised by G.D. Fahrenheit (1686-1736) a pioneer in establishment of thermometric scales. Originally he chose 0 to be the temperature of an ice and salt mixture (this was the minimum artificially achieved temperature in those days and he disliked negative temperatures!) and 96 to be the body temperature (he wanted the fundamental interval to be a multiple of 6). But as the body temperature keeps on changing and the particular ice-salt mixture cannot be obtained



(a)



(b)

FIG. 12.4 The level of liquid in a closed tube (thermometer) increases with temperature. The height at which it stands in the tube is a measure of the temperature.

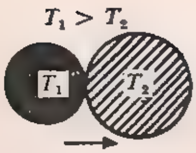


FIG. 12.3 Heat energy flows from a region of higher temperature to a region of lower temperature. The direction of flow of heat energy does not depend on the amount of heat energy contained in each body. The energy continues to flow until the temperatures of both the bodies in contact become equal.

NOTE The branch of science which deals with the measurement of high temperatures is known as *pyrometry*.

D.12.6 Thermometer A device for measuring the temperature of a body.

PRINCIPLE Any physical property of a substance which varies with temperature is used to measure temperature [e.g. expansion of a solid, liquid or gas, change in resistance (D.18.22), etc.]. See Table 12.3.

EXAMPLES Mercury thermometer, platinum resistance thermometer, constant volume hydrogen thermometer, etc.

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(iii) Its expansion should be uniform throughout the range of measurement, otherwise the degree markings will not be of equal size.

(iv) The expansion should be large so that the degree markings are reasonably apart.

(v) It should be easily distinguishable from the glass container.

(vi) It should be a good conductor of heat so that it can quickly attain the temperature of the body.

(vii) It should not change the temperature of the body appreciably, i.e. heat capacity (D.13.5) of the liquid should be low.

(viii) The difference between melting and boiling points should be large.

All of these conditions are satisfied by mercury, whereas alcohol satisfies only (ii), (iii), (iv) and (vii). In properties (i), (vi) and (viii) alcohol is inferior to mercury while in property (iv) it is better. Water, except for property (ii), is inferior to both mercury and alcohol in all other respects.

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D.12.12 Unit of Temperature Scale The value of one subdivision of the fundamental interval. See Table 12.4.

D.12.13 Thermometric Scales A scale on which the temperature of the body is expressed. See Table 12.4.

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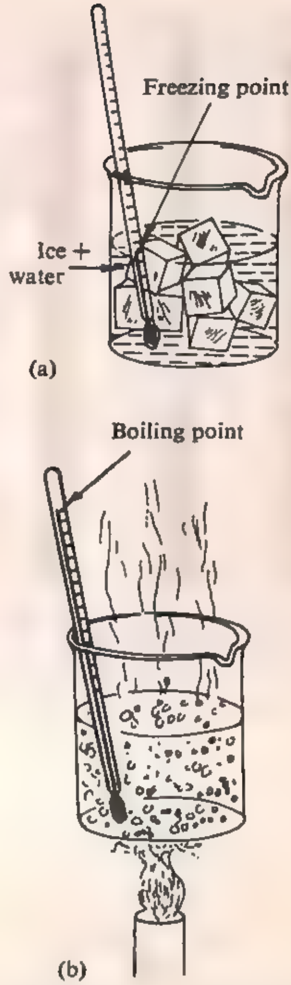


FIG. 12.4 The level of liquid in a closed tube (thermometer) increases with temperature. The height at which it stands in the tube is a measure of the temperature.

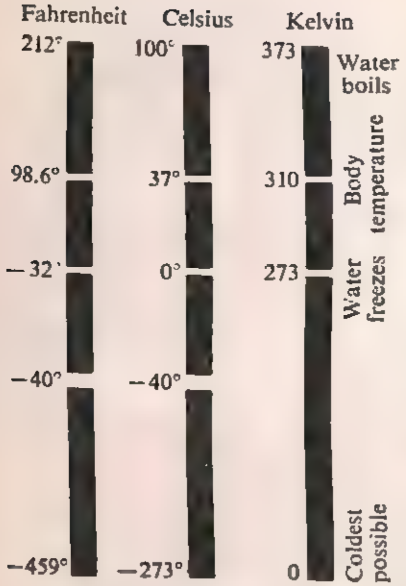


FIG. 12.5 Comparison of the three temperature scales.

TABLE 12.4 The four thermometric scales.

Name of scale	Celsius	Fahrenheit	Reaumer	Absolute
Lower fixed point (Ice point)	0	32	0	273.16
Upper fixed point (Steam point)	100	212	80	373.16
Division in fundamental interval	100	180	80	100
Symbol	°C	°F	°R	K
Read as	degree Celsius	degree Fahrenheit	degree Reaumer	Kelvin

easily, the two fixed points were later redefined. This scale is still widely used in U.S.A, U.K. and some other countries in non-scientific work.

(iii) The Reaumer scale was introduced by R.A. Reaumer (1683-1757). Why he chose the steam point as 80 is not very clear.

(iv) The absolute scale was introduced by Lord Kelvin (1824-1907). It later replaced all other scales in scientific work. The size of one unit in Celsius and Kelvin scales are equal. The zero of the absolute scale is theoretically the minimum possible temperature (however, this temperature can never be achieved practically).

(v) In most of the calculations where accuracy is not required, the ice point and the steam point in the absolute scale are taken to be 273 K and 373 K respectively. We will also follow this.

(vi) On the International Practical Temperature Scale (1968) recommended for scientific work, temperatures are expressed both in Kelvin and degree Celsius. The base unit in both the

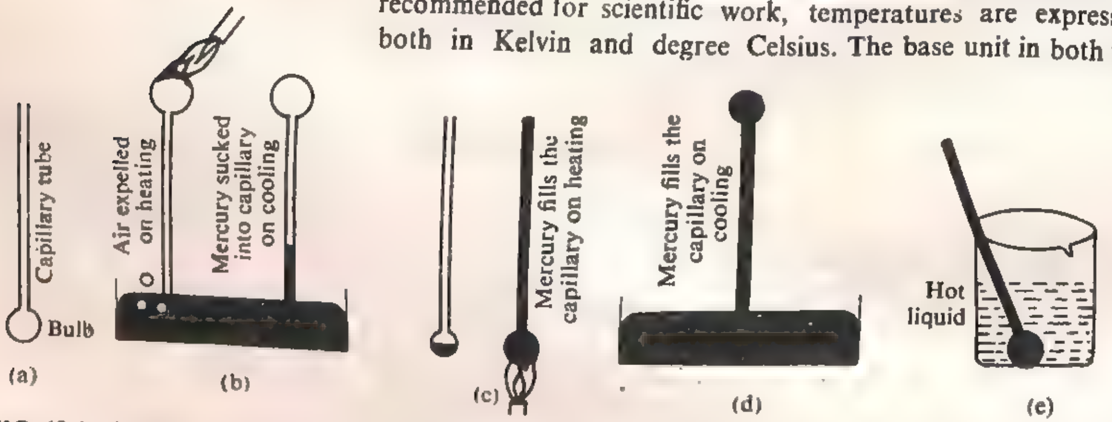


FIG. 12.6 Construction of mercury thermometer. (a) A glass bulb of required size is fused at the end of a long capillary tube. (b) The capillary tube is inverted into a mercury reservoir. The glass bulb is heated till some of the air from the tube passes through the mercury. On cooling some of mercury is sucked into the bulb. (c) The tube is inverted and the bulb is heated till all the air is expelled from the tube by the expanding mercury. (d) The tube is now quickly inverted into a mercury reservoir. When the tube is cooled it gets filled with mercury. (e) The bulb is kept in an oil bath maintained at a temperature greater than the maximum temperature to be measured by the thermometer. The mercury is allowed to overflow and after some time the upper end of the tube is sealed.

scale is Kelvin. The temperature difference may be expressed in Kelvin even when the individual temperatures are expressed in degree Celsius and vice-versa.

RELATION BETWEEN THE FOUR SCALES

$$\frac{C-\text{Fixed point}}{100}=\frac{F-\text{Fixed point}}{180} \qquad (E.12.1)$$

where C and F are the magnitudes of temperature on Celsius and Fahrenheit scales respectively. If the fixed point is the ice point,

$$\frac{C-0}{100}=\frac{F-32}{180}=\frac{R-0}{80}=\frac{K-273}{100} \qquad (E.12.2)$$

D.12.14 Mercury Thermometer A temperature measuring device which makes use of the expansion of mercury.

CONSTRUCTION See Fig. 12.6.

GRADUATION See Fig. 12.7.

NOTES (i) Before marking, the thermometer is left for a few days so that it can regain its shape and size.

(ii) The sensitivity or ability to measure small changes in temperature, can be increased by (a) taking a bulb of large size, (b) taking a capillary of narrow bore, (c) using a liquid of high coefficient of expansion (D.12.26).

LIMITATIONS (i) The bore of the tube may not be uniform. The actual degree will then not be of equal size.

(ii) If sufficient time is not allowed for cooling before markings are done, the actual zero will be at a lower level.

(iii) While making a measurement, the part of the mercury column outside the container is at a different temperature. The observed reading will therefore be slightly less than the actual reading.

(iv) After measuring a high temperature, a lower temperature must not be measured immediately. Sufficient time should be allowed for the bulb to contract.

D. 12.15 Maximum-Minimum Thermometer A thermometer designed to record the highest and lowest temperatures reached during a period of time.

CONSTRUCTION See Fig. 12.8.

WORKING PRINCIPLE (i) During the day time when the atmospheric temperature rises, the alcohol in the bulb D expands, pushing the mercury down in tube C. The index I_1 moves upward with the rising mercury thread in tube B. The index I_2 does not move downward.

(ii) When the atmospheric temperature decreases, the alcohol

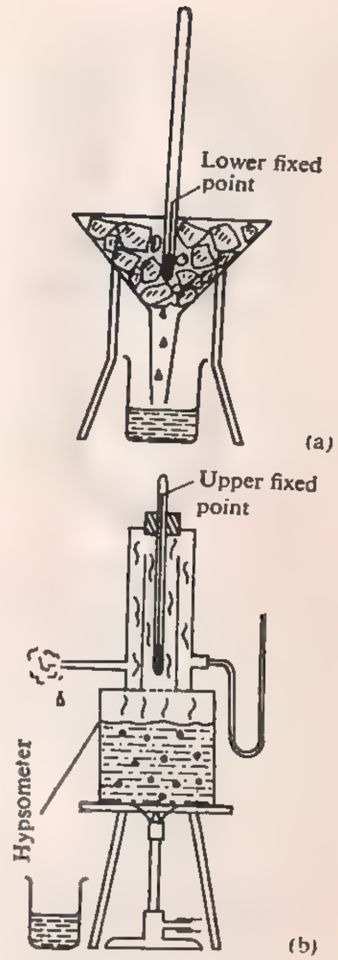


FIG. 12.7 Graduation of thermometer. (a) Lower fixed point. The thermometer is placed in a container of melting ice. When mercury thread becomes stationary, a line is marked there. (b) Upper fixed point. The thermometer is placed in a hypsometer such that the bulb does not touch the water. After a certain time when the mercury thread becomes stationary a line is marked there.

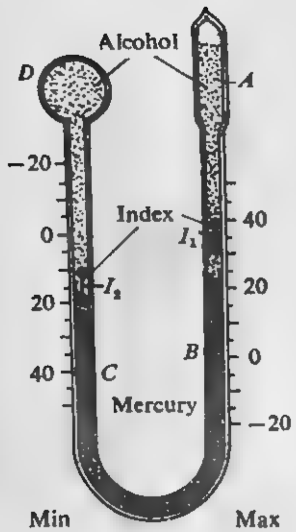


FIG. 12.8 Maximum-minimum thermometer. It is a U-shaped tube having two bulbs A and D. The U-tube is partly filled with mercury. The space above mercury in both the arms is filled with alcohol. The bulb D is completely filled while bulb A is kept half empty. Each arm of the U-tube has one steel index with a spring. The spring allows the index to move only upward. In one arm the temperature markings increase downward while in the other arm these increase upward.

in bulb *D* contracts and a gap is created between the alcohol and mercury level in tube *C*. In the gap, vapour pressure due to mercury is much less than the alcohol vapour pressure in bulb *A*. Due to this pressure difference, the mercury level together with the index I_2 moves upward in tube *C* without affecting index I_1.

(iii) The lower position of index I_1 gives the maximum temperature during a time interval while that of I_2 gives the minimum temperature.

(iv) After noting down the readings for a day, both the indexes are brought in contact with the mercury surface with the help of a small magnet.

NOTE This type of thermometer is used in meteorological work for recording maximum and minimum temperature during one day.

D. 12.16 Clinical Thermometer A mercury thermometer designed to measure the temperature of the human body.

CONSTRUCTION See Fig. 12.9.

PRINCIPLE One of the foremost requirements of the thermometer measuring the temperature of the human body is that when it is removed from the body, its reading should not change. This is achieved by a constriction near the bulb. When the thermometer is removed from the body, the mercury in the bulb contracts and the mercury thread breaks at the constriction. The thread in the tube thus remains in place to indicate the correct body temperature. The mercury remains in the tube until the thermometer is jerked to bring it down.

NOTE In places with extremely low atmospheric temperatures, such as the polar regions, the mercury may freeze (melting point −39°C). Coloured alcohol (melting point−117°C) is, therefore, preferred as the thermometer liquid in such locations.

12.3 EXPANSION OF SOLIDS

In a solid the atoms oscillate about their mean position and behave as if they were joined by springs. The spring length is equal to the mean distance between two atoms. At higher temperatures the increase in the kinetic energy of the atoms increases the amplitude of vibration. As a consequence the mean distance between two atoms (i.e. the spring length) increases, and the solid expands.

D. 12.17 Linear Expansion The phenomenon of change in length of an object with change in temperature.

SPECIFICATION The change in length measured with respect to the length at 0°C is proportional to (i) length at 0°C, and

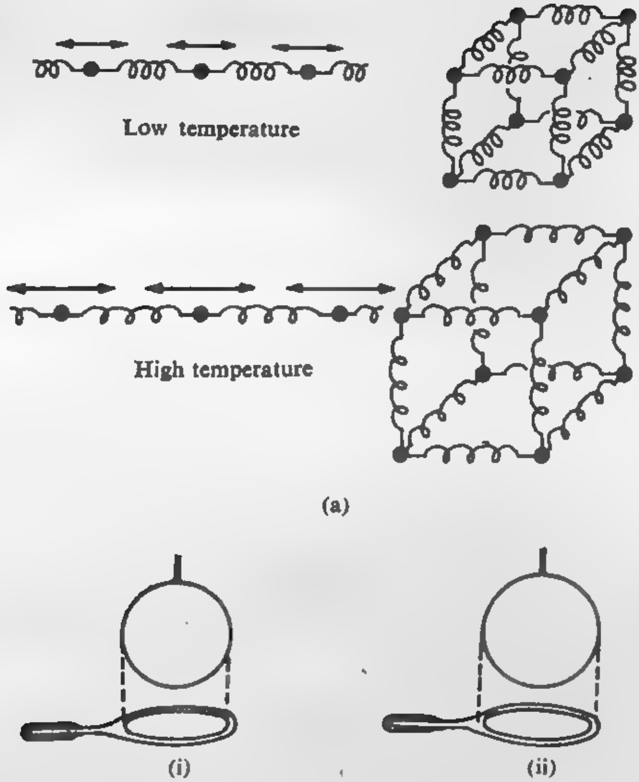


Fig. 12.10 (a) Atomic model of linear expansion. When a solid is heated the length of the spring increases. As a consequence length of the solid increases. (b) Ball and ring experiment. (i) At normal temperature the ball just passes through the ring. (ii) When the ball is heated it expands and cannot pass through the ring.

(ii) the rise in temperature above 0°C in degree Celsius.

MATHEMATICAL EXPRESSION

$$L_t - L_0 \propto L_0$$
$$\propto t$$
$$L_t - L_0 = \alpha L_0 t, \qquad \text{or}$$
$$L_t = L_0 (1 + \alpha t) \qquad (E.\ 12.3)$$

α is the constant of proportionality and is known as the coefficient of linear expansion (D. 12.18).

D. 12.18 Coefficient of Linear Expansion A measure of the linear expansion.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION α

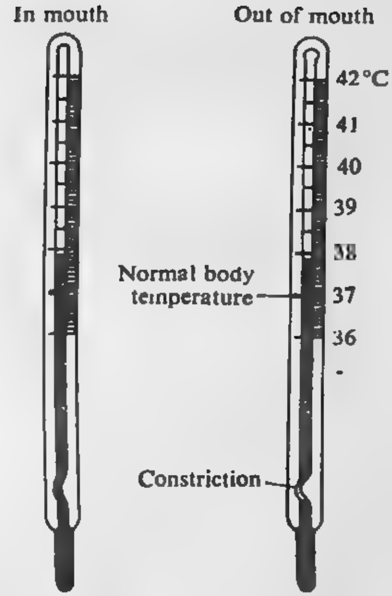


FIG. 12.9 A clinical thermometer. It is a mercury thermometer having a short temperature range, 36°C to 42°C. There is a mark at 37°C indicating the normal body temperature. The capillary has a constriction near the bulb. Here the capillary radius is very small. Mercury can pass through this constriction only when forced. The expansion in mercury caused by the body temperature forces it to move upward while it is forced to move down when the thermometer is jerked.

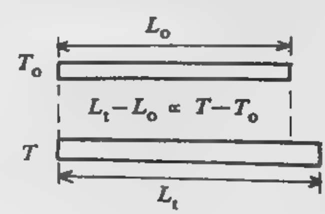


FIG. 12.11 Thermal expansion of a rod. The length of the rod increases as it is heated. The change in length is proportional to the change of temperature.

TABLE 12.5 Coefficient of linear expansion of some solids

	α ($\times 10^{-6}$ °C^{-1})
Aluminium	24
Brass	19
Brick	19
Carbon	
diamond	1.2
graphite	6
Copper	17
Concrete	7−12
Glass	
pyrex	9
ordinary	3
Gold	14
Ice	51
Iron	12
Invar	~0
Lead	30
Quartz	0.4
Rubber	80
Silver	20
Tungsten	4.5
Steel	12

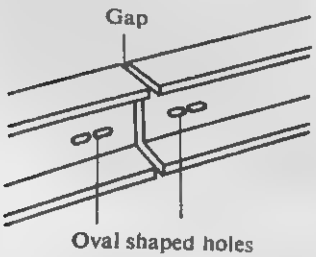


FIG. 12.12 A gap is always left between two adjacent railway lines to allow room for expansion. If this is not done, the railway lines will bend during hot weather causing derailment. The holes in the rails are oval shaped so that they can slide during expansion. In buildings also small gaps are left at places.

SPECIFICATION The increase in length per unit length caused by a rise in temperature of 1°C. Measured in per degree celsius (°C^{-1}).

MATHEMATICAL EXPRESSION

$$\alpha = \frac{\text{Change in length}}{\text{Original length} \times \text{change in temperature}}$$

$$= \frac{L_f - L_i}{L_i\,(t_f - t_i)} \qquad (E.\ 12.4)$$

NOTE The values of α from E. 12.3 and E. 12.4 seem to be different. Let from E. 12.3

$$L_f = L_0\,(1+\alpha t_f) \text{ and } L_i = L_0\,(1+\alpha t_i)$$

$$\frac{L_f}{L_i} = \frac{1+\alpha t_f}{1+\alpha t_i} = (1+\alpha t_f)(1+\alpha t_i)^{-1}$$

$$= (1+\alpha t_f)\,(1-\alpha t_i+\ldots)$$

$$= 1+\alpha\,(t_f - t_i) \text{ neglecting terms of } \alpha^2\text{, etc.}$$

This is the same as E. 12.4.

LIMITATIONS DUE TO THERMAL EXPANSION In many cases thermal expansion is troublesome and one has to take precautions to avoid damages.

1. Railway track See Fig. 12.12.

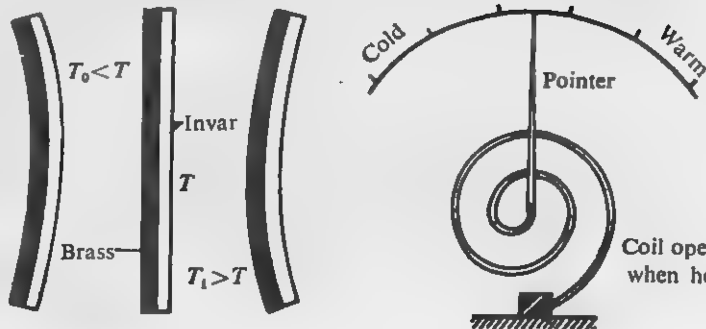
2. Steel bridges See Fig. 12.13.

3. Cracking of a thick glass tumbler Wares made from thick glass are likely to crack when a hot liquid is poured into them. Glass is a poor conductor of heat. Therefore, the inside of the glass becomes hot first and expands more than the outside. The force of expansion causes cracks in the glass vessel. Some glasses like pyrex do not expand much. Hence the glasswares made from these do not crack.

APPLICATIONS OF THERMAL EXPANSION Thermal expansion can be exploited to advantage in many ways.

1. Bimetallic strip It is a device made by welding two strips of different metals having different coefficients of linear expansions along their entire length. As the temperature changes, the strip bends due to the different amounts of expansion or contraction of the two metals. This property is used in constructing instruments such as thermostat, Fig. 12.14(b) (a device to maintain a constant temperature in electrical appliances, such as electric irons, refrigerators, furnaces, geysers, etc. by switching on and off the electrical circuit); fire alarm, Fig. 12.14(c); and thermometer, Fig. 12.14(d).

2. Metal tyre fixing While constructing the wheels of a bullock-cart, a steel tyre of slightly less diameter than the wooden wheel is taken. The steel tyre is heated and, as it ex-



(a) Bimettalic strip

(b) Thermometer

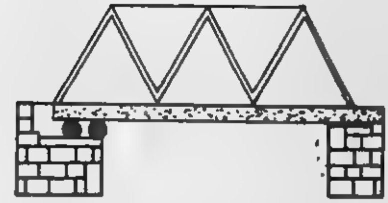
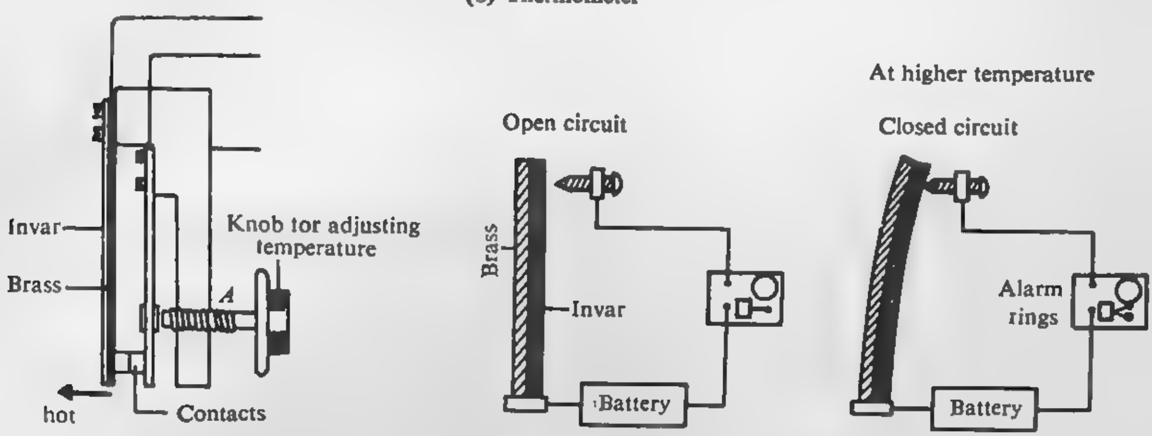


FIG. 12.13 One end of the bridge is fixed while the other is kept on rollers so that while expanding, the bridge can slide easily.



(c) Thermostat

(d) Fire alarm

FIG. 12.14 Bimettalic strip and its applications. (a) A bimettalic strip. On heating, the strip bends towards the metal having lower coefficient of linear expansion. On cooling, it bends towards the metal having higher coefficient of linear expansion. The extent of bending depends on the temperature. (b) A thermometer. As the strip bends the pointer attached to it moves on a scale graduated to read temperature. (c) A thermostat. At normal temperature the current flows through the circuit. When the temperature becomes higher than a preassigned value, the circuit breakes and heating stops. It is set at different temperatures by changing the distance between screw A and the straight portion of the strip. (d) A fire alarm. At certain high temperature, caused by fire, the bending of the bimettalic strip operates an electrical bell circuit causing a loud fire alarm to start.

pands, it is slipped on the wheel. On cooling it contracts and grips the wheel tightly.

3. *Riveting* It is a process of joining two metal plates or bars. See Fig. 12.15.

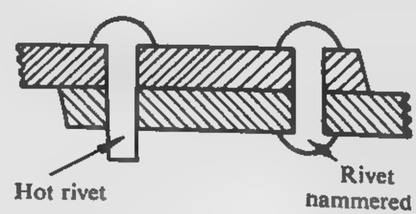


FIG. 12.15 Riveting. (a) A red hot rivet is placed between the holes of two metal bars or plates. (b) The rivet is hammered flat while still hot. On cooling the rivet contracts and the enormous force of contraction holds the bars tightly together.

D. 12.19 Superficial Expansion The phenomenon of change of area of an object with change in temperature.

SPECIFICATION The change in area measured with respect to the area at 0 C is proportional to the (i) area at 0°C and (ii) rise in temperature above 0 C.

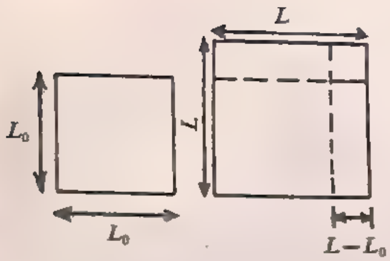


FIG. 12.16 Superficial expansion—area of a plate changes with temperature.

MATHEMATICAL EXPRESSION

$$A_t - A_0 \propto A_0$$
$$\propto t$$
$$A_t - A_0 = \beta A_0 t, \qquad \text{or}$$
$$A_t = A_0(1+\beta t) \qquad (E.\ 12.5)$$

β is the constant of proportionality and is known as the coefficient of superficial expansion (D. 12.20).

D. 12.20 Coefficient of Superficial Expansion A measure of the superficial expansion.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION β

SPECIFICATION The increase in area per unit area caused by a rise in temperature of 1°C. Measured in per degree Celsius (°C^{-1}).

MATHEMATICAL EXPRESSION

$$\beta = \frac{\text{Change in area}}{\text{Original area} \times \text{change in temperature}}$$
$$= \frac{A_f - A_i}{A_i(t_f - t_i)} \qquad (E.\ 12.6)$$

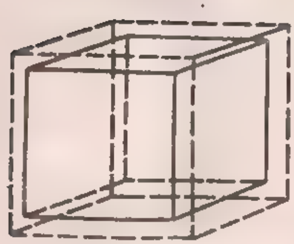


FIG. 12.17 When the temperature changes each side of the cube changes by an equal amount.

D. 12.21 Cubic (or Volume) Expansion The phenomenon of change of volume with change in temperature.

SPECIFICATION The change in volume measured with respect to the volume at 0°C is proportional to the (i) volume at 0°C and (ii) rise in temperature above 0°C in degree Celsius.

MATHEMATICAL EXPRESSION

$$v_t - v_0 \propto v_0$$
$$\propto t$$
$$v_t - v_0 = \gamma\, v_0\, t$$
$$v_t = v_0(1+\gamma\, t) \qquad (E.\ 12.7)$$

γ is the coefficient of proportionality and is known as coefficient of cubic expansion (D. 12.22).

D. 12.22 Coefficient of Cubic Expansion A measure of cubic expansion.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION γ

SPECIFICATION The increase in volume per unit volume for 1°C rise in temperature. Measured in per degree Celsius (°C^{-1}).

MATHEMATICAL EXPRESSION

$$\gamma = \frac{\text{Change in volume}}{\text{Original volume} \times \text{change in temperature}}$$
$$= \frac{v_f - v_i}{v_i(t_f - t_i)} \qquad (E.\ 12.8)$$

RELATION BETWEEN COEFFICIENT OF LINEAR AND SUPERFICIAL EXPANSION

$$a = a_0(1+\alpha t), \;\; b = b_0(1+\alpha t).$$
$$A_t = ab = a_0 b_0(1+\alpha t)^2$$
$$= A_0(1+2\alpha t+\alpha^2 t^2) \quad \text{Neglect } \alpha^2 \text{ term.}$$
$$A_t \approx A_0(1+2\alpha t) \tag{E.12.9}$$

Comparing E.12.5 and E.12.9, we get

$$\beta \approx 2\alpha \tag{E.12.10}$$

RELATION BETWEEN COEFFICIENT OF LINEAR AND CUBIC EXPANSION

$$a = a_0(1+\alpha t), \;\; b = b_0(1+\alpha t), \;\; c = c_0(1+\alpha t).$$
$$v_t = abc = a_0 b_0 c_0(1+\alpha t)^3$$
$$v_t \approx v_0(1+3\alpha t) \tag{E.12.11}$$

Comparing E.12.7 and E.12.11, we get

$$\gamma \approx 3\alpha \tag{E.12.12}$$

RELATION BETWEEN DENSITY AND COEFFICIENT OF CUBIC EXPANSION The change in temperature does not change the mass of the body or $m = v_{t_f} d_{t_f} = v_{t_i} d_{t_i}$.

or, or,

$$\frac{d_{t_f}}{d_{t_i}} = \frac{v_{t_i}}{v_{t_f}} = \frac{1}{1+\gamma(t_f-t_i)} \qquad d_{t_f} = \frac{d_{t_i}}{1+\gamma(t_f-t_i)} \tag{E.12.13}$$

Since $\gamma > 0$, $t_f > t_i$, $d_{t_f} < d_{t_i}$.

DETERMINATION OF COEFFICIENT OF LINEAR EXPANSION

Apparatus See Fig. 12.18.

Working principle See Fig. 12.18.

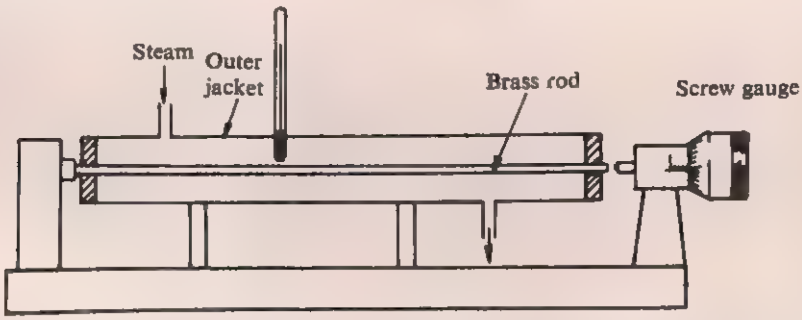


FIG. 12.18 Determination of coefficient of linear expansion. (i) Apparatus. A rod of given material about 100 cm in length and 0.5 cm in diameter is enclosed in a jacket. The jacket has a hole for fixing a thermometer. It is heated by passing steam. (ii) Measurement. (a) Before starting the experiment measure the length of the rod L_0, by a metre scale and the temperature T_0 of the chamber. (b) Advance the screw such that it just touches the free end of the rod. Note the reading of the screw gauge and then unscrew it. (c) Heat the rod by passing steam through the jacket. When the temperature of the chamber becomes constant (T) again move the screw such that it comes in contact with the expanded end of the rod. The difference between the two readings of the screw gauge gives $L-L_0$, $t = T-T_0$. Determine α from Eq. 12.4.

12.4 EXPANSION OF LIQUIDS

Like solids, liquids also expand. The only relevant expansion in liquids is volume expansion because liquids do not have a fixed length or surface area. Further, as the liquid is always in some container, two kinds of cubic expansions are defined depending upon whether the expansion of the container is taken into account or not.

TABLE 12.6 Coefficient of cubic expansion for some liquids.

	γ ($\times 10^{-5}$ °C^{-1})
Alcohol	
ethyl	112
methyl	120
Benzene	124
Carbon tetrachloride	124
Ether	166
Gasoline	96
Glycerine	50
Mercury	18
Turpentine	90
Water	21

D.12.23 Apparent Expansion The cubic expansion of a liquid when the cubic expansion of the container is not taken into account.

SPECIFICATION See D.12.21. Replace γ by γ_a.

D.12.24 Coefficient of Apparent Expansion A measure of the apparent expansion of liquids.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION γ_a

SPECIFICATION See D.12.22. Replace γ by γ_a in E.12.8.

D.12.25 Real Cubic Expansion The cubic expansion of a liquid when the cubic expansion of the container is taken into account.

SPECIFICATION See D.12.21. Replace γ by γ_r.

D.12.26 Coefficient of Real Expansion A measure of the real cubic expansion of a liquid.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION γ_r

SPECIFICATION See D.12.22. Replace γ by γ_r in E.12.8.

RELATION BETWEEN COEFFICIENT OF APPARENT AND REAL EXPANSION

$$\gamma_r = \gamma_a + \text{coefficient of cubic expansion of the container} \tag{E.12.14}$$

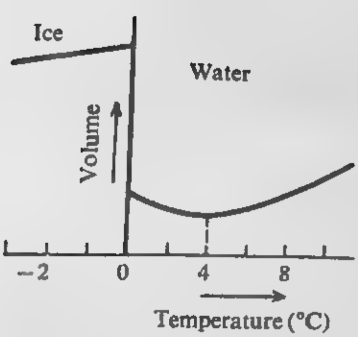


FIG. 12.19 Anomalous expansion of water. The volume of water is minimum at 4°C (density is maximum).

D.12.27 Anomalous Expansion of Water Water exhibits a peculiar expansion behaviour with temperature. It contracts as the temperature rises from 0°C to 4°C. As the temperature increases beyond 4°C it starts expanding and continues to do so. Water, therefore, has minimum volume (and hence maximum density) at 4°C.

NOTES (i) No other liquid shows this kind of behaviour.

(iii) The density increases with temperature from 0°C to 4°C, becomes maximum at 4°C, and then continues to decrease.

(iii) The coefficient of volume expansion is negative between 0°C and 4°C.

IMPORTANCE OF ANOMALOUS EXPANSION In the colder regions where atmospheric temperature goes to 0°C or below, the ano-

malous expansion plays an important part in the survival of aquatic life.

Let the water in a given lake be at 10°C. When the atmospheric temperature becomes less than 10°C, say 9°C, the top layer of water shifts to the bottom of the lake because water at 9°C is more dense than water at 10°C. This process continues till the whole lake achieves a temperature lower than 10°C. This cycle continues till the temperature of 4°C is reached. The whole lake is now at 4°C. As the atmospheric temperature decreases further, the top layer does not shift to the bottom of the lake as it is less dense than the lower layers which are at 4°C. The temperature of the top layer keeps on decreasing and finally it freezes and attains the temperature of the surroundings. The water below the ice remains at 4°C and the fishes live happily there.

12.5 EXPANSION OF GASES

Like liquids, gases also do not have a fixed length or surface area. Therefore, here also only volume expansion can be studied. The expansion of gases is so large compared to the expansion of the container that expansion of the container can be neglected for all practical purposes. Thus we have only the real expansion. In case of gases there are three variables, volume, pressure and temperature. In order to study the dependence of volume on temperature, the pressure is kept constant.

The phenomenon of expansion of gases can be utilised in several ways. A dent in a table tennis ball is removed by putting it into hot water. The air inside the ball expands, removing the dent. The engines in scooters, cars, etc. utilize the principle of expansion of gases. When petrol is ignited, hot gases are formed and the engine is driven by the pressure developed by the expansion of these gases. However, the expansion of gases also puts some limitations. If air is pumped too hard in a cycle tyre on a cool morning, the tyre is likely to burst in the day time when the temperature is higher. In racing cars, the heat produced by friction raises the temperature of the tyre considerably. The expansion of air may burst the tyre.

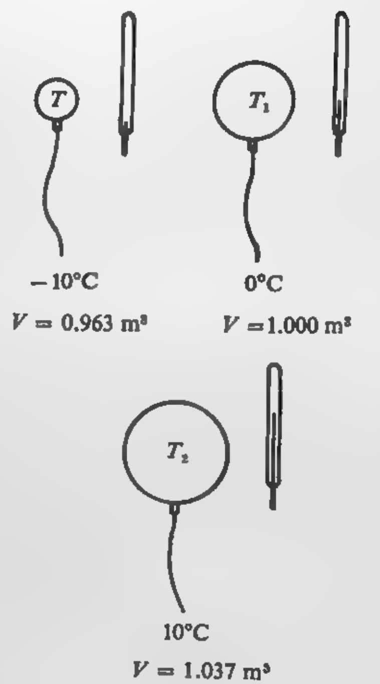


FIG. 12.20 Gases expand as temperature increases.

D.12.28 Cubic Expansion of Gas See D.12.21.

D.12.29 Coefficient of Cubic Expansion of Gas See D.12.22.

MAGNITUDE At normal pressure and at 0°C

$$\gamma = \frac{1}{273}\ °C^{-1} = 3.66 \times 10^{-3}\ °C^{-1} \qquad (E.12.15)$$

NOTES (i) From E.12.7, $v_t = 0$ when $1+\gamma t = 0$, or $t = -\frac{1}{\gamma} = -273$°C. If t is less than -273°C, v_t will become negative

which simply *cannot* be possible. Hence the minimum possible temperature is $-273°C$ (or 0 K on absolute scale).

(ii) Since the expansion of gases is independent of their nature over a wide range of temperature scale, all the standard thermometers used in very accurate scientific work or used to calibrate other thermometers are really gas thermometers using chiefly hydrogen and nitrogen. (The one at National Physical Laboratory, New Delhi, is a constant pressure hydrogen thermometer.)

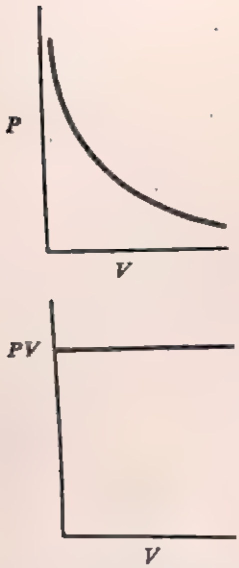


FIG. 12.21 Pressure-volume relationship when temperature of a gas is held constant. (a) P is inversely proportional to volume (Boyle's law). (b) PV is a constant.

12.6 GAS LAWS

Three variables, volume, pressure and temperature determine the behaviour of a gas. The following three laws provide relations between these three quantities.

LAW 13: BOYLE'S LAW (Relation between pressure and volume at constant temperature)

At constant temperature, volume of the gas is inversely proportional to the pressure of the gas.

MATHEMATICAL EXPRESSION

$$P \propto \frac{1}{V} \qquad \text{Temperature constant}$$

or

$$PV = \text{constant} \qquad (E.\ 12.16)$$

LAW 14: CHARLES' LAW (Relation between volume and temperature at constant pressure)

At constant pressure, volume of the gas is directly proportional to the temperature of the gas.

MATHEMATICAL EXPRESSION

$$V \propto T \qquad \text{Pressure constant, } T \text{ in Kelvin}$$

or

$$V = \text{constant} \times T \qquad (E.\ 12.17)$$

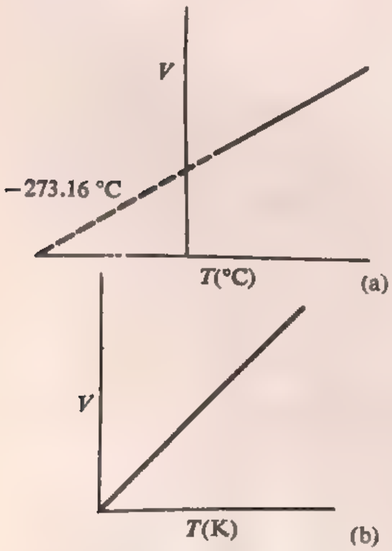


FIG. 12.22 Charles' law—volume of a gas, at constant pressure, is directly proportional to its temperature. (a) The volume decreases uniformly as the temperature decreases and becomes zero at $-273.16°C$, the lowest possible temperature. (b) Graph between V and T when T is in Kelvin.

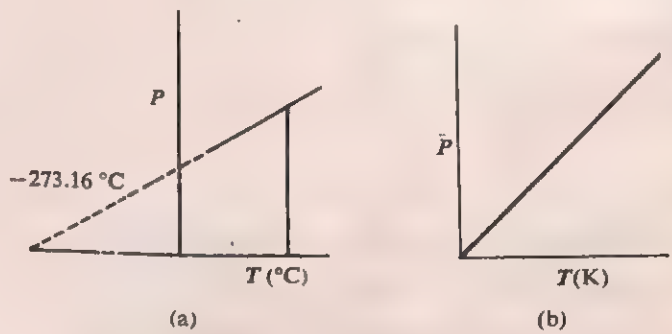


Fig. 12.23 Pressure-temperature law. The pressure of a gas, at constant volume, is directly proportional to its temperature. (a) Pressure of the gas is zero at -273.16 °C. (b) Graph between P and T when temperature is expressed in Kelvin.

LAW 15: PRESSURE—TEMPERATURE LAW (Relation between pressure and temperature at constant volume)
At constant volume, pressure of the gas is directly proportional to the temperature of the gas.

MATHEMATICAL EXPRESSION

$$P \propto T \qquad \text{Volume constant, } T \text{ in Kelvin}$$

or

$$P = \text{constant} \times T \qquad (E.\ 12.18)$$

NOTE These three laws can be combined into a single equation, i.e.

$$PV = RT \qquad (E.\ 12.19)$$

This equation is known as the *ideal gas equation.* R is a constant, known as Gas Constant.

SOLVED EXAMPLES

EXAMPLE 12.1 A few years back clinical thermometers in India were marked in °F (these are still available). Only recently the government of India decided that these should be calibrated in °C (SI unit). The normal body temperature is 98.6°F. How much will it read on °C and K scales?

Solution $T_F = 98.6°F$. Let the temperature on Celsius and Kelvin scales be T_C and T_K respectively. We know that,

$$\frac{T_C - 0°C}{100°C} = \frac{T_F - 32°F}{180°F}$$

or

$$T_C = \frac{5°C}{9°F}(T_F - 32°F)$$

$$= \frac{5°C}{9°F}(98.6°F - 32°F) = 37°C.$$

Further,

$$\frac{T_K - 273\text{ K}}{100\text{ K}} = \frac{T_C - 0°C}{100°C}$$

or $T_K = T_C\ \text{K°C}^{-1} + 273\text{ K}$
$= 37°C\ \text{K°C}^{-1} + 273\text{ K} = 310\text{ K}.$

Answer The body temperature on the celsius and Kelvin scales are 37°C and 310 K respectively.

NOTE If one uses a relation of the type $(T_C - 0)/100 = (T_F - 32)/180$, then T_C and T_F are the magnitudes of temperature on celsius and Fahrenheit scales. In this case,

$$T_C = \frac{5}{9}(T_F - 32) \text{ and } T_F = \frac{9}{5}T_C + 32.$$

EXAMPLE 12.2 Determine the temperature at which readings on celsius scale will be same as that on Fahrenheit scale.

Solution Let T be the required temperature. According to the question, $T_C = T_F$, or $T_C°C = T_F°F$. Now,

$$T_C = \frac{5}{9}(T_F - 32) = \frac{5}{9}(T_C - 32), \text{ or}$$

$$4T_C = -160, \text{ or}$$

$$T_C = -40°$$

Answer At $-40°$, the readings of the two scales will coincide.

EXAMPLE 12.3 On a particular day the mercury thread in a thermometer stood below the 0°C mark. The thread was 3 mm away from the 0°C mark and 153 mm away from the 100°C mark. Determine (i) length of the fundamental interval, (ii) length of the unit degree, and (iii) temperature of the day.

Solution Distance of the mercury thread from 0°C mark = 3 mm = 0.003 m, and the distance of mercury thread from 100°C mark = 153 mm = 0.153 m.

(i) Fundamental interval is the distance between 0°C mark and 100°C mark.

Distance between 0°C and 100°C mark = distance between 100°C and mercury thread − distance between 0°C and mercury thread

= 0.153 m − 0.003 m = 0.15 m.

(ii) Length of unit degree = length of the fundamental interval/number of degrees

= 0.15 m/100°C = 0.0015 m°C^{-1}.

(iii) Since the mercury stands below 0°C, the temperature of the day will be less than 0°C, i.e. negative. The distance of the mercury thread from 0°C will therefore be negative.

Temperature = distance of mercury thread from 0°C mark/length of the unit degree
= −0.003 m/0.0015 m°C^{-1}
= −2°C.

Answer (i) The fundamental interval is 0.15 m, (ii) length of the unit degree is 0.0015 m°C^{-1} and (iii) the temperature of the day is −2°C.

EXAMPLE 12.4 A steel tape is calibrated at 20.00°C. It reads 27.100 cm at 5.00°C. Determine the true reading.

Solution Since the tape was calibrated at 20°C, it will give correct reading only at 20°C. If the measurements are done at other temperatures, the readings should be converted to 20°C.

We have T_i = 5°C, T_f = 20°C. L_o = 27.1 cm = 0.271 m, $\alpha = 12\times10^{-6}$ °C^{-1} and $t = T_f - T_i$ = 20°C − 5°C = 15°C. Now,

$L_t = L_o(1+\alpha t)$
= 0.271 m × (1 + 12 × 10^{-6} °C^{-1} × 15°C)
= 0.271 × 1.000 18 m = 0.271 05 m

Answer The true reading is 0.271 05 m (27.105 cm).

EXAMPLE 12.5 An iron ball of 5.0 cm diameter is 0.010 mm too large to pass through the hole of a brass ring at a temperature of 40.00°C. Find the temperature of the ring at which the ball will just fit into it.

Solution We are asked to find the temperature at which the brass ring diameter will be 5.00 cm. Hence D_t = 5 cm = 0.05 m, D_o = 5 cm − 0.001 cm = 0.049 99 m, T_o = 40°C, and $\alpha = 17\times10^{-6}$ °C^{-1}.

$D_t = D_o(1+\alpha t)$, or

$$t = \frac{D_t - D_o}{D_o\alpha} = \frac{0.05\text{ m} - 0.049\,99\text{ m}}{0.4999\text{ m}\times17\times10^{-6}\,°\text{C}^{-1}}$$
$$= \frac{0.000\,01}{0.049\,99\times17}\times10^{6}\,°\text{C} = 11.8°\text{C}$$

Now, $t = T_f - T_i$, or

$T_f = T_i + t$ = 40°C + 11.8°C
= 51.8°C

Answer At 51.8°C the ball will just fit into the ring.

EXAMPLE 12.6 When railway lines are laid a gap is left between two rails to allow room for expansion. If this is not done, the railway line will bend in the summer months. Suppose in our country, lines 10.0000 m long are laid on a day when the temperature is 20°C. In the summer, the temperature goes to as much as 48°C. Find the necessary gap to be left so that two lines just touch each other in the summer months.

Solution L_o = 10 m, T_f = 48°C, T_i = 20°C, $\alpha = 12\times10^{-6}$ °C^{-1} and $t = T_f - T_i$ = 48°C − 20°C = 28°C.

$L_t = L_o(1+\alpha t)$
= 10 m × (1 + 12 × 10^{-6} °C^{-1} × 28°C)
= 10.0034 m.

Change in length = $L_t - L_o$ = 10.0034 m − 10.0000 m = 0.0034 m.

The line expands in both the directions since none of its ends is fixed. In one direction it will

expand 0.0034 m/2 = 0.0017 m. The other line will also expand by this amount. Hence the total room for expansion should be 2×0.0017 m = 0.0034 m

Answer The gap between two adjacent railway lines should be 0.0034 m (0.34 cm).

Suggestion Do this problem for one end of the rail fixed and the other end free.

EXAMPLE 12.7 If the coefficient of superficial expansion of copper is $34 \times 10^{-6}\,°C^{-1}$, determine the coefficient of linear and volume expansion.

Solution $\beta = 34 \times 10^{-6}\ °C^{-1}$. By definition $\beta = 2\alpha$, and $\gamma = 3\alpha$.

$$\alpha = \beta/2 = \frac{34 \times 10^{-6}\,°C^{-1}}{2} = 17 \times 10^{-6}\,°C^{-1}.$$

$$\gamma = 3\alpha = 3 \times 17 \times 10^{-6}\,°C^{-1}$$
$$= 51 \times 10^{-6}\,°C^{-1}.$$

Answer The coefficients of linear and volume expansion of copper are $17 \times 10^{-6}\ °C^{-1}$ and $51 \times 10^{-6}\,°C^{-1}$ respectively.

EXAMPLE 12.8 The radius of a sphere of iron at 0°C is 0.5000 m. Find the change in volume if it is heated to a temperature of 700°C.

Solution $r = 0.5$ m, $T_f = 700°C$, $T_i = 0°C$, $\gamma = 36 \times 10^{-6}\,°C^{-1}$, and $t = T_f - T_i = 700°C$.

$$V_o = \frac{4\pi}{3} r^3 = \frac{4\pi}{3} \times (0.5\text{ m})^3.$$

$$V_t = V_o(1 + \gamma t), \text{ or}$$

$$V_t - V_o = V_o\gamma t = \frac{4\pi}{3} \times (0.5\text{ m})^3 \times 36 \times 10^{-6}\ °C^{-1} \times 700°C = 0.0132\text{ m}^3.$$

Answer The change in the volume is 0.0132 m^3.

EXAMPLE 12.9 A sphere of copper is at 0°C. At what temperature will its volume be doubled?

Solution $T_i = 0°C$, $\gamma = 51 \times 10^{-6}\ C^{-1}$ and $V_t = 2V_o$.

$$V_t = V_o(1 + \gamma t), \text{ or}$$

$$t = \frac{V_t - V_o}{\gamma V_o} = \frac{2V_o - V_o}{\gamma V_o}$$

$$= \frac{1}{\gamma} = \frac{1}{51 \times 10^{-6}\,°C^{-1}} = 19\,608°C.$$

Answer The volume of the copper sphere will be doubled at 19 608°C.

NOTE Copper will not remain solid at this temperature.

EXAMPLE 12.10 The capacity of the iron petrol tank of Vijay Super two wheeler scooter is about 8 litres. It was filled upto the brim on a cold winter morning when the temperature was 4°C. If the scooter was thereafter not used, how much petrol will overflow if, on that day, the temperature rises upto 23°C?

Solution $V_o = 8$ litres = 8000 cc = 0.008 m^3, $T_i = 4°C$, $T_f = 25°C$, $\gamma_{iron} = 36 \times 10^{-6}\ °C^{-1}$, $\gamma_{petrol} = 96 \times 10^{-5}\,°C^{-1}$ and $t = T_f - T_i = 21°C$. In this problem we should first calculate the volume of the petrol tank and petrol at 25°C.

$$V_{tank} = V_o(1 + \gamma_{iron} t)$$
$$= 0.008\text{ m}^3 \times (1 + 36 \times 10^{-6}\,°C \times 21°C)$$
$$= 0.008\,006\text{ m}^3.$$

$$V_{petrol} = V_o(1 + \gamma_{petrol} t)$$
$$= 0.008\text{ m}^3 \times (1 + 96 \times 10^{-5}\,°C^{-1} \times 21°C)$$
$$= 0.008\,161\text{ m}^3.$$

At 25°C, the petrol tank can hold only 0.0080 06 m^3 petrol. Hence,

Amount of petrol overflown = volume of petrol − volume of tank

$$= 0.008\,161\text{ m}^3 - 0.008\,006\text{ m}^3$$
$$= 0.000\,155\text{ m}^3 \simeq 0.000\,16\text{ m}^3$$
$$= 0.16\text{ litre}.$$

Answer 0.16 litre petrol will overflow.

NOTE At the current rate, about Rs 6 per litre, the loss will be Re 0.96.

EXAMPLE 12.11 A hydrogen balloon at the earth's surface, where pressure is 10^5 Nm^{-2}, has a volume of 4 m^3. As it rises in the air, the atomspheric pressure drops. Will its volume increase or decrease? Determine the volume of the balloon at a height of 40 km, where the pressure is about 320 Nm^{-2}. Assume that the temperature remains constant.

Solution $P_i = 10^5$ Nm^{-2}, $P_f = 320$ Nm^{-2} and $V_i = 4$ m^3. According to the question tem-

Solution Distance of the mercury thread from 0°C mark = 3 mm = 0.003 m, and the distance of mercury thread from 100°C mark = 153 mm = 0.153 m.

(i) Fundamental interval is the distance between 0°C mark and 100°C mark.

Distance between 0°C and 100°C mark = distance between 100°C and mercury thread − distance between 0°C and mercury thread

= 0.153 m − 0.003 m = 0.15 m.

(ii) Length of unit degree = length of the fundamental interval/number of degrees

$= 0.15\ \text{m}/100°\text{C} = 0.0015\ \text{m}°\text{C}^{-1}$.

(iii) Since the mercury stands below 0°C, the temperature of the day will be less than 0°C, i.e. negative. The distance of the mercury thread from 0°C will therefore be negative.

Temperature = distance of mercury thread from 0°C mark/length of the unit degree

$= -0.003\ \text{m}/0.0015\ \text{m}°\text{C}^{-1}$

$= -2°\text{C}$.

Answer (i) The fundamental interval is 0.15 m, (ii) length of the unit degree is 0.0015 $\text{m}°\text{C}^{-1}$ and (iii) the temperature of the day is −2°C.

EXAMPLE 12.4 A steel tape is calibrated at 20.00°C. It reads 27.100 cm at 5.00°C. Determine the true reading.

Solution Since the tape was calibrated at 20°C, it will give correct reading only at 20°C. If the measurements are done at other temperatures, the readings should be converted to 20°C.

We have $T_i = 5°\text{C}$, $T_f = 20°\text{C}$. $L_o = 27.1$ cm = 0.271 m, $\alpha = 12\times10^{-6}\ °\text{C}^{-1}$ and $t = T_f - T_i = 20°\text{C} - 5°\text{C} = 15°\text{C}$. Now,

$L_t = L_o(1+\alpha t)$

$= 0.271\ \text{m}\times(1+12\times10^{-6}\ °\text{C}^{-1}\times15°\text{C})$

$= 0.271\times1.000\ 18\ \text{m} = 0.271\ 05\ \text{m}$

Answer The true reading is 0.271 05 m (27.105 cm).

EXAMPLE 12.5 An iron ball of 5.0 cm diameter is 0.010 mm too large to pass through the hole of a brass ring at a temperature of 40.00°C. Find the temperature of the ring at which the ball will just fit into it.

Solution We are asked to find the temperature at which the brass ring diameter will be 5.00 cm. Hence $D_t = 5$ cm = 0.05 m, $D_o = 5$ cm − 0.001 cm = 0.049 99 m, $T_o = 40°\text{C}$, and $\alpha = 17\times10^{-6}\ °\text{C}^{-1}$.

$D_t = D_o(1+\alpha t)$, or

$$t = \frac{D_t - D_o}{D_o\alpha} = \frac{0.05\ \text{m} - 0.049\ 99\ \text{m}}{0.4999\ \text{m}\times17\times10^{-6}\ °\text{C}^{-1}}$$

$$= \frac{0.000\ 01}{0.049\ 99\times17}\times10^{6}\ °\text{C} = 11.8°\text{C}$$

Now, $t = T_f - T_i$, or

$T_f = T_i + t = 40°\text{C} + 11.8°\text{C}$

$= 51.8°\text{C}$

Answer At 51.8°C the ball will just fit into the ring.

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Solution $L_o = 10$ m, $T_f = 48°\text{C}$, $T_i = 20°\text{C}$, $\alpha = 12\times10^{-6}\ °\text{C}^{-1}$ and $t = T_f - T_i = 48°\text{C} - 20°\text{C} = 28°\text{C}$.

$L_t = L_o(1+\alpha t)$

$= 10\ \text{m}\times(1+12\times10^{-6}\ °\text{C}^{-1}\times28°\text{C})$

$= 10.0034$ m.

Change in length $= L_t - L_o = 10.0034$ m − 10.0000 m = 0.0034 m.

The line expands in both the directions since none of its ends is fixed. In one direction it will

expand 0.0034 m/2 = 0.0017 m. The other line will also expand by this amount. Hence the total room for expansion should be 2×0.0017 m = 0.0034 m

Answer The gap between two adjacent railway lines should be 0.0034 m (0.34 cm).

Suggestion Do this problem for one end of the rail fixed and the other end free.

EXAMPLE 12.7 If the coefficient of superficial expansion of copper is $34\times10^{-6}\,°C^{-1}$, determine the coefficient of linear and volume expansion.

Solution $\beta = 34\times10^{-6}\ °C^{-1}$. By definition $\beta = 2\alpha$, and $\gamma = 3\alpha$.

$$\alpha = \beta/2 = \frac{34\times10^{-6}\,°C^{-1}}{2} = 17\times10^{-6}\,°C^{-1}.$$

$$\gamma = 3\alpha = 3\times17\times10^{-6}\,°C^{-1}$$
$$= 51\times10^{-6}\,°C^{-1}.$$

Answer The coefficients of linear and volume expansion of copper are $17\times10^{-6}\ °C^{-1}$ and $51\times10^{-6}\,°C^{-1}$ respectively.

EXAMPLE 12.8 The radius of a sphere of iron at 0°C is 0.5000 m. Find the change in volume if it is heated to a temperature of 700°C.

Solution $r = 0.5$ m, $T_f = 700°C$, $T_i = 0°C$, $\gamma = 36\times10^{-6}\,°C^{-1}$, and $t = T_f - T_i = 700°C$.

$$V_o = \frac{4\pi}{3}\,r^3 = \frac{4\pi}{3}\times(0.5\text{ m})^3.$$

$$V_t = V_o(1+\gamma t),\ \text{or}$$

$$V_t - V_o = V_o\gamma t = \frac{4\pi}{3}\times(0.5\text{ m})^3\times36\times10^{-6}$$
$$°C^{-1}\times700°C = 0.0132\text{ m}^3.$$

Answer The change in the volume is 0.0132 m^3.

EXAMPLE 12.9 A sphere of copper is at 0°C. At what temperature will its volume be doubled?

Solution $T_i = 0°C$, $\gamma = 51\times10^{-6}\ °C^{-1}$ and $V_t = 2V_o$.

$$V_t = V_o(1+\gamma t),\ \text{or}$$

$$t = \frac{V_t - V_o}{\gamma V_o} = \frac{2V_o - V_o}{\gamma V_o}$$

$$= \frac{1}{\gamma} = \frac{1}{51\times10^{-6}\,°C^{-1}} = 19\ 608°C.$$

Answer The volume of the copper sphere will be doubled at 19 608°C.

NOTE Copper will not remain solid at this temperature.

EXAMPLE 12.10 The capacity of the iron petrol tank of Vijay Super two wheeler scooter is about 8 litres. It was filled upto the brim on a cold winter morning when the temperature was 4°C. If the scooter was thereafter not used, how much petrol will overflow if, on that day, the temperature rises upto 23°C?

Solution V_o = 8 litres = 8000 cc = 0.008 m^3, $T_i = 4°C$, $T_f = 25°C$, $\gamma_{iron} = 36\times10^{-6}\,°C^{-1}$, $\gamma_{petrol} = 96\times10^{-5}\,°C^{-1}$ and $t = T_f - T_i = 21°C$. In this problem we should first calculate the volume of the petrol tank and petrol at 25°C.

$$V_{tank} = V_o(1+\gamma_{iron}t)$$
$$= 0.008\text{ m}^3\times(1+36\times10^{-6}\,°C\times21°C)$$
$$= 0.008\ 006\text{ m}^3.$$

$$V_{petrol} = V_o(1+\gamma_{petrol}t)$$
$$= 0.008\text{ m}^3\times(1+96\times10^{-5}\,°C^{-1}\times21°C)$$
$$= 0.008\ 161\text{ m}^3.$$

At 25°C, the petrol tank can hold only 0.0080 06 m^3 petrol. Hence,

Amount of petrol overflown = volume of petrol − volume of tank

$$= 0.008\ 161\text{ m}^3 - 0.008\ 006\text{ m}^3$$
$$= 0.000\ 155\text{ m}^3 \simeq 0.000\ 16\text{ m}^3$$
$$= 0.16\text{ litre}.$$

Answer 0.16 litre petrol will overflow.

NOTE At the current rate, about Rs 6 per litre, the loss will be Re 0.96.

EXAMPLE 12.11 A hydrogen balloon at the earth's surface, where pressure is 10^5 Nm^{-2}, has a volume of 4 m^3. As it rises in the air, the atomspheric pressure drops. Will its volume increase or decrease? Determine the volume of the balloon at a height of 40 km, where the pressure is about 320 Nm^{-2}. Assume that the temperature remains constant.

Solution $P_i = 10^5$ Nm^{-2}, $P_f = 320$ Nm^{-2} and $V_i = 4$ m^3. According to the question tem-

perature is constant. Boyle's law will, therefore, be applicable. We have $PV =$ constant. If P decreases, then in order to keep PV constant, V must increase. That is, the volume of the balloon will increase.

We have $PV =$ constant, or $P_iV_i = P_fV_f$

$$\text{or} \quad V_f = \frac{P_iV_i}{P_f} = \frac{10^5\ \text{Nm}^{-2} \times 4\ \text{m}^3}{320\ \text{Nm}^{-2}}$$

$$= 1250\ \text{m}^3.$$

Answer The volume of the balloon will increase as it rises. At a height of 40 km its volume will be 1250 m³.

Example 12.12 500 litres of oxygen gas is at 27°C. What will be the volume if the temperature is raised to 54°C? The pressure remains constant.

Solution $V_i = 500$ litres $= 0.5\ \text{m}^3$. Since the pressure is constant, volume can be calculated from Charles' law. The temperatures must be converted to Kelvin. $T_i = 270°\text{C} = (273+27)\text{K} = 300\text{K}$, and $T_f = 54°\text{C} = (273+54)\text{K} = 327$ K. From Charles' law $V =$ constant $\times T$, or $V/T =$ constant.

$$\frac{V_i}{T_i} = \frac{V_f}{T_f},$$

$$\text{or} \quad V_f = \frac{V_iT_f}{T_i} = \frac{0.5\ \text{m}^3 \times 327\ \text{K}}{300\ \text{K}}$$

$$= 0.545\ \text{m}^3 = 545\ \text{litres}.$$

Answer The final volume will be 545 litres.

Example 12.13 The gas inside a cylinder is heated till its pressure doubles. If there is no change in the volume, find the initial temperature. Given that the final temperature is 200°C.

Solution $P_f = 2\ P_i$, $T_f = 200°\text{C} = (273+200)\ \text{K} = 473$ K. Since the volume of the gas is constant, the pressure-temperature law will be applicable. We have $P =$ constant $\times T$ or $P/T =$ constant, or

$$\frac{P_i}{T_i} = \frac{P_f}{T_f}$$

$$\text{or} \quad T_i = \frac{P_iT_f}{P_f} = \frac{473\ \text{K}}{2} = 236.5\ \text{K}$$

$$= (236.5-273)°\text{C} = -36.5°\text{C}.$$

Answer The initial temperature of the gas is $-36.5°$C.

PROBLEMS

12.1 The melting and boiling points of lead are 330°C and 1170°C respectively. What will be these numbers on Kelvin and Fahrenheit scale?

12.2 Find the readings on Celsius scale if it is (i) double, and (ii) half of the reading on Fahrenheit scale.

12.3 Determine the temperature on Kelvin scale such that it is (i) double, and (ii) three times of the reading on Celsius scale.

12.4 On a day the maximum and minimum temperatures were 20°C and 40°C respectively. Determine these temperatures on Fahrenheit and Kelvin scales.

12.5 Calculate the theoretically possible coldest temperature in °F.

12.6 In a certain thermometer 4°C and 100°C are 16 cm apart. How far will the 42°C mark be from the 0°C mark?

12.7 The distances of 0°C and 100°C marks from the mercury level, which stands between 0°C and 100°C, is 4.0 cm and 16.0 cm respectively. (i) What is the length of the fundamental interval? (ii) What is the distance between two successive marks? (iii) How far will the 49°C mark be from the 0°C mark?

12.8 In a certain mercury thermometer the 0°C and 100°C marks are 63 mm and 213 mm from the bottom of the bulb. When placed in a hot water tub, the mercury stops at a height of 138 mm. What is the temperature of the water?

12.9 In a certain mercury thermometer while measuring the temperature of a hot liquid it was observed that the 0°C mark, 100°C mark and the top of the mercury level are 160 mm, 40 mm and 64mm from the top of the tube respectively. What temperature does the thermometer indicate?

12.10 A steel ruler is 30.00 cm long at 15°C when calibrated. On a day in June, the temperature rises to as much as 46°C. Find the length of the the ruler on that day. If the ruler is made of copper what will be the increase in length?

12.11 A steel measuring tape is 5.0000 m long at 5°C. At what temperature will it be 0.5 cm longer?

12.12 The tungsten filament in a light bulb is about 1.00 cm long. When the bulb is switched on, the filament temperature changes by as much as 1900°C. What will be the new filament length?

12.13 A brass ring has a diameter of 40 cm at a temperature of 50°C. Find the diameter of the ring at 200°C.

12.14 An iron tyre of inner diameter 992.0 mm at 20°C is to be fitted over a wooden wheel of diameter 1000 mm. To what temperature should the tyre be raised so that it just fits over the wheel? This method is used for preparing the wheels of bullock carts.

12.15 The length of a certain bridge is 2.0000 km at 0°C. The temperature in the region goes to as high as 46°C. If the bridge is made of iron, find the change in length.

12.16 It is noticed that when a 100.00 cm long chromium wire is cooled from 20°C to 0°C, its length becomes 99.99 cm. Find the coefficient of linear expansion of chromium.

12.17 A rod 3000 mm long when heated from 8°C to 88°C expands by 1.5 mm. Determine the coefficient of linear expansion.

12.18 Find the coefficient of superficial and volume expansion of first three substances given in Table 12.5.

12.19 At what temperature will the length of a 1000 mm long copper rod be doubled? Initial temperature 0°C.

12.20 An iron plate at 0°C has a circular hole of diameter 1.0 cm. What will be the diameter of the hole at 100°C?

12.21 The coefficient of volume expansion of iron is 51×10^{-6} C^{-1}. What will be the coefficient of linear and superficial expansion?

12.22 A flat round plate at 10°C made of aluminium has a radius of 21 cm. What will be its area at 100°C?

12.23 A flat square steel plate of length 1000.0 mm is heated from 20°C to 200°C. Find the new area.

12.24 At what temperature will the area of a lead square plate of side 1000 mm be doubled? Assume that the plate does not melt at this temperature. Initial temperature 0°C.

12.25 A vessel made of pyrex glass has a volume of 5.0 litres at 30°C. It is filled with turpentine. What is the (i) volume of vessel at 60°C, (ii) volume of the turpentine at 60°C, and (iii) volume of the turpentine overflowing at 60°C?

12.26 A pyrex glass beaker is filled to the top with 400.0 cm³ of mercury at 16°C. How much mercury runs out of the beaker as the temperature is raised to 100°C?

12.27 600 g liquid of coefficient of volume expansion 3×10^{-3} °C^{-1} occupies a volume of 0.51 litres at 278 K. The temperature of the liquid is raised to 348°C. Find the density and the volume of the liquid.

12.28 The gas inside a cylinder is compressed to one fourth of its original volume. If the final pressure is 10^5 Nm^{-2}, determine the initial pressure.

12.29 The pressure of a gas changes from 1 atmosphere to 0.25 atmosphere at constant temperature. What is the ratio of the final and initial volumes?

12.30 An air bubble is taken from the surface to the bottom of a 100 m deep lake. If the volume of the bubble at the bottom of lake is 1 cc, calculate its volume at the surface. Assume that there is no temperature change.
[*Hint*: pressure at the surface of lake is 1 atmosphere (10^5 Nm^{-2}). At the bottom of the lake, the pressure is 1 atmosphere $+\rho gh$]

12.31 Gas at 22°C is contained in a cylinder with a movable piston. When the temperature is raised the piston moves out keeping the pressure constant. The volume of the gas at 102°C is 1.50 litre. Find the initial volume of the gas.

12.32 Oxygen at a temperature of 27°C is contained in a container at a pressure of 3×10^5 Nm^{-2}. What will be the pressure if the temperature of the container is raised to 127°C?

12.33 By what per cent will the pressure inside a car tyre rise, when the temperature changes from 30°C to 80°C? Assume that there is no change in the volume of the tyre.

13 Measurement of Heat Energy

Two bodies at different temperatures and in contact exchange heat energy. The exchange of heat energy follows the overall law of conservation of energy. The knowledge of the amount of heat transferred from one body to another forms the basis of measurement of the quantities associated with the study of heat energy.

13.1 BASIC CONCEPTS

We will begin with certain definitions used in the study of heat energy.

D.13.1 Unit of Heat SI unit of heat is Joule (J) because heat is a form of energy.

NOTE Still another unit for heat energy, calorie (D.13.2), which is not an SI unit, is used by many authors. All the calculations in this book are done in SI units only.

D.13.2 Calorie A base CGS unit (D.1.4) of heat energy.

WRITTEN REPRESENTATION cal

SPECIFICATION Amount of heat required to raise the temperature of 1 gram of water by 1°C.

Or

Amount of heat required to raise the temperature of 1 gram of water from 14.5°C to 15.5°C.

NOTE The second specification is known as 15° calorie. The temperature range is included in the definition because specific heat capacity (D.13.4) of water is not independent of the temperature range. For most practical purposes, however, the variation in the range 0°C to 100°C can be neglected.

D.13.3 Kilocalorie A larger CGS unit of heat energy, equal to 1000 cal.

TYPE OF QUANTITY Derived CGS unit

WRITTFN REPRESENTATION kcal

SPECIFICATION 1 kcal = 1000 cal

RELATION BETWEEN CALORIE AND JOULE

$$1 \text{ cal} = 4.1868 \text{ J} \qquad (E.\ 13.1)$$

NOTE In this book, wherever required, 1 cal = 4.2 J.

D.13.4 Specific Heat Capacity (*or, simply, Specific Heat*) A measure of the heat holding capacity of the substance.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION *c, s*

SPECIFICATION The quantity of heat required to raise the temperature of one kilogram of a substance by one Kelvin (or by 1 C). Measured either in Joule per kilogram per Kelvin ($J\,kg^{-1}\,K^{-1}$) or joule per kilogram per degree Celsius ($J\,kg^{-1}\,°C^{-1}$). See Note (vi) D.12.13.

NOTES (i) If the unit of heat is cal then the unit of specific heat capacity is cal $gm^{-1}\,°C^{-1}$ (or kcal $kg^{-1}\,°C^{-1}$). In this unit specific heat capacity of water is 1 cal $gm^{-1}\,°C^{-1}$.

(ii) For gases two kinds of specific heat capacities are defined: one measured by keeping volume of the gas constant (c_v) and the other measured by keeping pressure of the gas constant (c_p).

(iii) The specific heat capacity is not an absolute constant. It does vary with temperature.

(iv) The high specific heat capacity of water plays an important role in keeping temperature changes to a minimum near seashores. In the day time, water absorbs a large amount of heat energy. This is released to the surroundings at night. This prevents the fall of temperature at night.

TABLE 13.1 Specific heat capacities of some substances (for solids and liquids around 20°C and for gases at NTP).

Substance	c ($Jkg^{-1}\,°C^{-1}$)
Alcohol	2500
Aluminium	920
Brass	395
Copper	390
Concrete	840
Glass	420 – 840
Human body	3486
Ice	2100
Iron	460
Lead	130
Mercury	139
Silver	235
Steel	462
Water	4200
Wood	1764
Air	1050
Helium	5208
Oxygen	920
Steam	1974

Note : Among solids and liquids, water has the highest specific heat capacity.

D.13.5 Heat Capacity (*old name Thermal Capacity*) A measure of the heat energy possessed by a body.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION *C*

SPECIFICATION The quantity of heat energy required to raise the temperature of a body through 1 K or 1 C. Measured in Joule per Kelvin ($J\,K^{-1}$) or Joule per degree Celsius ($J\,°C^{-1}$).

MATHEMATICAL EXPRESSION From the definition of specific heat capacity, the amount of heat required to raise the temperature of a body of unit mass by 1 K = c.

C = amount of heat required to raise the temperature of a body of mass m by 1 K = mc.

$$C = mc \qquad (E.13.2)$$

NOTES (i) The word 'specific' appearing before a physical quantity is now exclusively used only to mean 'per unit mass'. If the physical quantity is denoted by a capital letter [e.g. C for heat capacity, L for latent heat (D.13.8)] the specific quantity is denoted by the corresponding lower case letter [e.g. c for the specific heat capacity, etc.]

(ii) Water has the second highest heat capacity among all the substances; the highest is that of helium.

D.13.6 Transfer of Heat Energy A measure of the total amount of heat energy gained or lost by a body.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION Q

SPECIFICATION The heat energy gained or lost when the temperature changes from T_i to T_f. Measured in joules (J).

MATHEMATICAL EXPRESSION From E.13.2 and specification

$$Q = C\,(T_f - T_i) = mc\,(T_f - T_i) \qquad (E.13.3)$$

NOTES (i) Water is used in car radiators to cool the engine because for a given Q, $T_f - T_i$ is least for water on account of its high specific heat capacity. Thus, the rise in temperature will be least for water (see Example 13.4).

(ii) When $Q > 0$, $T_f > T_i$, the body gains heat. When $Q < 0$, $T_f < T_i$, the body loses heat.

13.2 CHANGE OF STATE

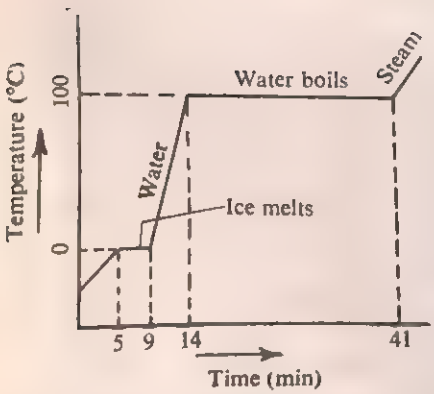


FIG. 13.1 Graph of temperature vs time when heat at a constant rate of 84×10^3 J per minute is supplied to 1 kg of ice.

The addition or removal of heat from a body does not always change its temperature. This happens when a solid liquefies or a liquid boils, Fig. 13.1.

(*a*) *From solid to liquid* In a solid, vibrating atoms are assumed to be joined to each other by springs, whereas in a liquid the atoms are free to move throughout the volume of the liquid. In order to convert a solid into liquid, the springs between atoms must be broken. At a certain temperature, known as the *melting point*, the whole of the energy supplied to the solid is used up in breaking the springs. Since there is no increase in the kinetic energy of the atoms, the temperature of the material does not change. This energy which must be supplied to break the lattice structure is known as the latent heat of fusion (D.13.9).

(*b*) *From liquid to solid* When a liquid is cooled, the kinetic energy of the molecules decreases and they come nearer to each other. At the melting point, the molecules are so much closer to each other, that these cannot escape from the attractive force of their neighbours and the lattice structure appears. In this transition, atoms lose kinetic energy which is given to the sur-

roundings. The temperature of the material will not decrease unless all the atoms lose their excess kinetic energy.

(*c*) *From liquid to gas* Normally the molecules of a liquid are not able to escape from the surface because of (i) the strong downward cohesive force at the surface which pulls them down and (ii) the downward pressure exerted by the gases above the liquid surface. In order to convert a liquid into gas, energy must be supplied to overcome these two forces. At the *boiling point*, all the energy supplied goes to overcome these forces and there is no increase in kinetic energy of the molecules. The temperature, therefore, remains constant. This energy supplied at constant temperature is the latent heat of vaporisation (D.13.10).

(*d*) *From gas to liquid* When a gas is cooled, the agitated motion of the molecules is slowed down, and the average distance of separation between two molecules decreases. At a certain temperature, known as the boiling point, the forces between two molecules become strong enough to restrict their motion to a part of the available volume. In this state, the kinetic energy of the molecules is much less than the kinetic energy in the gaseous state. The balance of energy is released to the surrounding and the gas liquefies.

D.13.7 Isothermal Transformation of State A change of state (e.g. solid to liquid or liquid to gas) without change in temperature.

D.13.8 Latent Heat A measure of heat energy required to produce an isothermal transformation of state.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION L

SPECIFICATION The amount of heat energy absorbed or released in an isothermal transformation of state. Measured in joules(J).

D. 13.9 Specific Latent Heat of Fusion A measure of the energy needed to break the lattice structure.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION l_f

SPECIFICATION The amount of heat energy required to convert 1 kilogram of a solid to a liquid without change in temperature. Measured in joules per kilogram (J kg^{-1}).

NOTE When 1 kg of liquid is converted to solid, heat energy equal to l_f must be removed from the liquid.

D. 13.10 Specific Latent Heat of Vaporization A measure of the energy required to overcome the cohesive forces between molecules.

TABLE 13.2 Specific latent heat of some substances.

Substance	l_f ($\times 10^3$ J kg^{-1})	l_v ($\times 10^3$ J kg^{-1})
Alcohol (ethyl)	104.7	854.1
Gold	64.5	1578.4
Helium	5.0	20.9
Lead	24.7	870.8
Mercury	11.7	297.3
Nitrogen	25.5	201.0
Oxygen	13.8	213.5
Silver	87.9	2344.6
Water	336	2260

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION l_v

SPECIFICATION The amount of heat required to convert 1 kilogram of a liquid to the vapour state at a pressure of 101 325 Nm^{-2}, without change of temperature. Measured in joules per kilogram (J kg^{-1}).

NOTES (i) There is a third kind of latent heat namely specific latent heat of sublimation. It is defined as the quantity of heat required to change unit mass of a substance from the solid to the vapour state without change of temperature.

(ii) When 1 kg of vapour condenses to the liquid at boiling point, the amount of heat released to the surroundings is l_v.

(iii) I kg of steam would cause more severe burn than 1 kg of boiling water because steam releases latent heat of vaporisation as well.

D. 13.11 Calorific Value A measure of the heat energy liberated by a fuel during burning.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION Calorific value

SPECIFICATION The amount of heat energy liberated by the complete combustion of one kilogram of a fuel, the water formed being assumed to condense to the liquid state. Measured in joule per kilogram (J kg^{-1}).

NOTES (i) Another widely used unit is calorie per gram (cal g^{-1}).

(ii) In the human body, the food after digestion enters the blood. Here it is oxidised (which is nothing but slow burning) and provides us with energy.

TABLE 13.3 Calorific values (kJ kg^{-1}) of some items of daily consumption.

Item	*Calorific value*
Boiled potatoes	3400
Bread	10 000
Butter	29 000
Cheese	16 800
Chocolate	23 000
Egg	7 000
Fresh fruit	2 000
Green vegetable	1 500
Olive oil	29 000
Peas	4 200
Sugar	16 000
Petrol	50 000
Coal	28 000

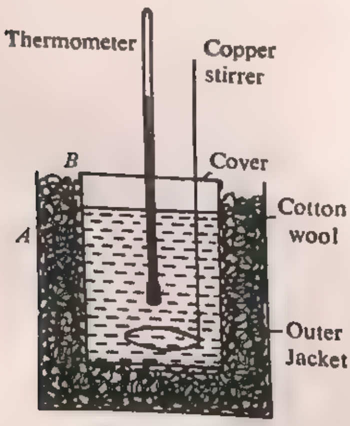


FIG. 13.2 A calorimeter. It contains an outer vessel A made of a poor conductor of heat like wood. A copper vessel B is placed inside the outer vessel A. The copper vessel contains a liquid of known specific heat (usually water). The air between the two vessels prevents loss of heat. A stirrer, to keep various parts of liquid at the same temperature, and a thermometer is placed in the liquid through the holes in a cover made from a nonconducting material.

13.3 CALORIMETRY

D.13.12 Calorimetry The branch of science dealing with the measurement of quantity of heat.

NOTE The specific heat capacities, specific latent heats, calorific value of fuels and heats of combustion, reaction and solution are determined in this field.

D. 13.13 Calorimeter An apparatus used for determining quantities of heat evolved, absorbed or transferred.

CONSTRUCTION See Fig. 13.2.

WORKING PRINCIPLE A body at different temperature than the calorimeter and its contents is allowed to come in contact with the contents of the calorimeter. The heat energy is exchanged till the calorimeter and its contents attain a uniform temperature. The law of conservation of energy gives

$$\text{Heat lost} = \text{Heat gained} \qquad (E.\ 13.4)$$

D. 13.14 Water Equivalent A quantity which can replace the calorimeter in all calculations.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION W

SPECIFICATION The mass of water which will have the same heat capacity as the calorimeter and its contents. Measured in kilogram (kg).

MATHEMATICAL EXPRESSION

Heat capacity of calorimeter $= mc$

Heat capacity of water $= Wc_w$

From the specification

$$Wc_w = mc \text{ or}$$

$$W = \frac{mc}{c_w} \qquad (E.\ 13.5)$$

NOTE If the calorimeter is filled with water, then the water equivalent of the calorimeter and its contents is simply equal to the water equivalent of the calorimeter+mass of the water.

D. 13.15 Bomb Calorimeter An instrument for measuring heat produced by the combustion of a fuel.

CONSTRUCTION See Fig. 13.3.

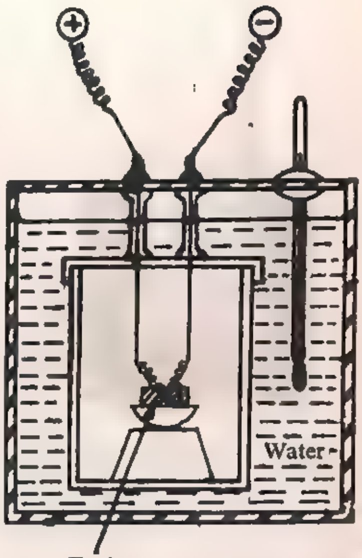


FIG. 13.3 Bomb calorimeter.

13.4 DETERMINATIONS USING CALORIMETER

(*a*) *Specific heat capacity of a solid* (i) Determine the weight of the solid body (M kg).

(ii) Heat the solid in a steam chamber such that it does not come in contact with the steam. Note the steady temperature of the solid body (T°C).

(iii) Take a calorimeter of known mass (m kg). Fill it about two-thirds with water and determine the mass of the water (W kg). Note the temperature of the calorimeter and its contents (T_i °C).

(iv) Quickly transfer the solid to the calorimeter. Stir the water in the calorimeter and note the highest temperature reached (T_f °C).

(v) Let the specific heat capacity of solid, copper (material of calorimeter) and water be c_s J kg^{-1} °C^{-1}, 390 J kg^{-1} °C^{-1}, and 4200 J kg^{-1} °C^{-1} respectively.

Heat lost by solid $= Mc_s\,(T_f - T)$ J

Heat gained by water+calorimeter $= (390m + 4200W) \times (T_f - T_i)$ J

Heat lost = Heat gained

$$Mc_s\,(T_f - T) = (390m + 4200W)\,(T_f - T_i)$$

or,

$$c_s = \frac{(390m + 4200W)}{M}\,\frac{T_f - T_i}{T_f - T} \qquad (E.\ 13.6)$$

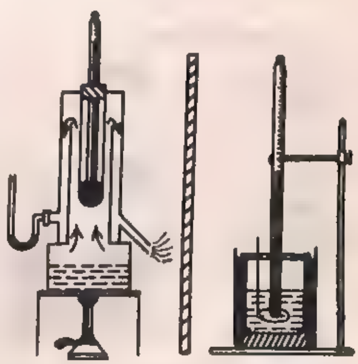


FIG. 13.4 Determination of specific heat of solid. A solid is heated in a steam chamber such that it does not touch the water. When its temperature becomes constant it is quickly transferred to a calorimeter. The contents of the calorimeter are stirred vigorously till maximum temperature is attained.

LIMITATIONS No matter what precautions are taken, some heat is always lost by the solid while transferring it to the calorimeter. T used in the calculations, therefore, is slightly higher than the actual value.

FIG. 13.5 Determination of specific latent heat of fusion of ice. Dry ice is added slowly to warm water, at about 10°C more than room temperature, in a calorimeter. The ice is dried with the help of a filter paper. The addition of ice is continued till the water temperature is about 5°C less than the room temperature.

(*b*) *Specific heat capacity of liquid* Here all the steps remain same as in the previous experiment. W_l kg of a liquid is taken in the calorimeter, instead of water. A solid, which does not react with the liquid, of known specific heat capacity c_l J kg^{-1} °C^{-1} is taken.

Heat lost by solid = Heat gained by liquid+calorimeter

$$Mc_s(T_f - T) = (390m + c_l W_l)(T_f - T_i)$$

$$c_l = \frac{Mc_s(T_f - T)}{W_l(T_f - T_i)} - \frac{390\text{ m}}{W_l} \qquad (E.\ 13.7)$$

(*c*) *Specific latent heat of fusion of ice* (i) Take a calorimeter of known mass (m kg).

(ii) Add some water of known mass in the calorimeter (W kg).

(iii) Heat the calorimeter such that its temperature is raised by about 5°C above room temperature (T_i °C).

(iv) Add a dry ice cube in the water. Stir the water keeping the ice completely under water, till it melts completely. Add more ice if necessary such that final water temperature is about 5°C below the room temperature (T_f °C).

(v) Weigh the calorimeter to determine the mass of ice added to the water (M kg).

(vi) Let specific latent heat of fusion of ice = L_f J kg^{-1}.

Heat gained by ice in melting = $M\,l_f$ J.

Heat gained by water obtained from melting of ice = 4200 MT_f J.

Heat gained = Heat lost

$$ML_f + 4200\,MT_f = (390m + 4200W)(T_i - T_f).$$

$$L_f = \frac{(390m + 4200W)(T_i - T_f)}{M} - 4200\,T_f \quad (E.\ 13.8)$$

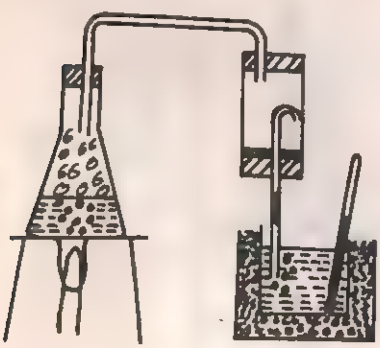


FIG. 13.6 Determination of specific latent heat of vaporisation. Steam is passed for some time through the calorimeter till the temperature of the water is about 30°C higher than the room temperature. The steam temperature at the given atmospheric pressure is taken from the standard tables or measured by a thermometer.

(*d*) *Specific latent heat of vaporization of water* In this experiment steam is passed through water in the calorimeter for some time. Let the mass of steam condensed be M kg, and the final temperature be T_f. The temperature of the steam T at the atmospheric pressure is noted from the table. Let the specific latent heat of vaporization be L_v J kg^{-1}.

Heat gained by water+calorimeter = $(390m + 4200W)$
$\times(T_f - T_i)$ J

Heat lost by steam in condensing = ML_v J

Heat lost by water produced from condensing steam = 4200 $M(T - T_f)$ J

$$\text{Heat lost} = \text{Heat gained}$$
$$ML_v + 4200\,M\,(T-T_f) = (390m + 4200\,W)(T_f - T_i).$$

or,

$$L_v = \frac{(390m+4200W)(T_f-T_i)}{M} - 4200\,(T-T_f) \quad (E.\ 13.9)$$

SOLVED EXAMPLES

EXAMPLE 13.1 The heat capacity of a 5.4 kg object is 4536 J°C^{-1}. Determine the specific heat capacity of the material of the object.

Solution $m = 5.4$ kg and $C = 4536$ J°C^{-1}. The heat capacity C is

$$C = mc$$

or $$c = \frac{C}{m} = \frac{4536\ \text{J°C}^{-1}}{5.4\ \text{kg}}$$
$$= 840\ \text{J kg}^{-1}\ \text{°C}^{-1}.$$

Answer The specific heat capacity of the material of the object is 840 J kg^{-1} °C^{-1}.

EXAMPLE 13.2 How much heat energy is required to change the temperature of 100g water from 10°C to 40°C?

Solution $m = 100$ g $= 0.1$ kg, $T_i = 10$°C, $T_f = 40$°C and $c = 4200$ J kg^{-1} °C^{-1}.

Heat energy required to raise the temperature from 10°C to 40°C

$$= mc(T_f - T_i) = 0.1\ \text{kg} \times 4200\ \text{J kg}^{-1}\,\text{°C}^{-1} \times (40\text{°C} - 10\text{°C})$$
$$= 12\,600\ \text{J}$$

Answer The required heat energy is 12 600J

EXAMPLE 13.3 A 10.0 g lead bullet travelling at a speed of 100 ms^{-1} hits a wooden block and stops. Find the rise in temperature of the bullet on impact if the whole of the kinetic energy is converted into heat energy.

Solution $m = 10$ g $= 0.01$ kg, $v_i = 100$ms^{-1}, $v_f = 0$, and $c = c_{lead} = 130$ J kg^{-1} °C^{-1}.

Change in kinetic energy of the bullet

$$= \frac{1}{2}\,m(v_i^2 - v_f^2) = \frac{0.01\ \text{kg}}{2} \times (100\ \text{ms}^{-1})^2$$
$$= 50\ \text{J}$$

According to the question this energy is converted into heat energy of the bullet. The gain of heat energy by the bullet will be $mc\,\Delta T$, where ΔT is the change in the temperature of the bullet. We have, therefore,

$$mc\,\Delta T = 50\ \text{J, or}$$
$$\Delta T = \frac{50\ \text{J}}{mc} = \frac{50\ \text{J}}{0.01\ \text{kg} \times 130\ \text{J kg}^{-1}\,\text{°C}^{-1}}$$
$$= 38.5\text{°C}.$$

Answer The temperature of the bullet will change by 38.5°C.

EXAMPLE 13.4 A fiat car radiator contains about 10.000 litre of water. During a one hour run, the temperature of the water rises by 30°C. (i) Find the amount of heat transferred to the water by the engine. (ii) If the radiator is filled with ethyl alcohol instead of water, what would be the rise of temperature?

Solution V = volume of water = 10 litre = 10^4cm^3 = 0.01 m^3, m = mass of water = $V \times$ density = 0.01 m$^3 \times 1000$ kg m^{-3} = 10 kg, ΔT = rise in temperature = 30°C.

$c_{water} = 4200$ J kg^{-1} °C^{-1}, and $c_{alcohol} = 2500$ J kg^{-1} °C^{-1}.

(i) Heat transferred by engine to water = $mc_{water}\,\Delta T$

$= 10 \text{ kg} \times 4200 \text{ J kg}^{-1} \text{°C}^{-1} \times 30\text{°C}$
$= 1.26 \times 10^6$ J.

(ii) If ethyl alcohol is used instead of water, then heat energy supplied to the alcohol will remain the same. In this case if ΔT is the rise of temperature then we have,

$$mc_{\text{alcohol}}\,\Delta T = 1.26 \times 10^6 \text{ J, or}$$

$$\Delta T = \frac{1.26 \times 10^6 \text{ J}}{10 \text{ kg} \times 2500 \text{ J kg}^{-1} \text{°C}^{-1}} = 50.4\text{°C}.$$

Answer The heat transferred to water by the engine is 1.26×10^6 J. The rise in the temperature of ethyl alcohol will be 50.4°C.

Suggestion Do this problem for 50°C rise of water temperature.

Example 13.5 2.000 kg of ethyl alcohol is heated by an immersion heater for 250s. If the temperature of the alcohol rises from 20.0°C to 70.0°C, find (i) heat supplied to the alcohol and (ii) power of the heater.

Solution $m = 2$ kg, $t = 250$ s, $T_i = 20\text{°C}$, $T_f = 70.0\text{°C}$, and $c = 2500 \text{ J kg}^{-1} \text{°C}^{-1}$. $\Delta T = T_f - T_i = 70\text{°C} - 20\text{°C} = 50\text{°C}$.

(i) Heat supplied to alcohol by heater = heat gained by alcohol $= mc\,\Delta T = 2 \text{ kg} \times 2500 \text{ J kg}^{-1} \text{°C}^{-1} \times 50\text{°C}$

$$= 2.5 \times 10^5 \text{ J}$$

(ii) Power of the heater = Energy supplied/time elapsed

$$= \frac{2.5 \times 10^5 \text{ J}}{250 \text{ s}} = 1000 \text{ W}.$$

Answer The immersion heater supplies 2.5×10^5 J energy to ethyl alcohol. The power of the heater is 1000 W.

Example 13.6 A blacksmith, while moulding a part of a hammer, inserts a hot iron piece of mass 100 g in 1000 g of water at a temperature of 29.5°C. If the final temperature of water is 35.0°C, calculate the initial temperature of the iron piece.

Solution $m_{\text{iron}} = 100 \text{ g} = 0.1$ kg, $m_w = 1000 \text{ g} = 1$ kg, $T_i = 29.5\text{°C}$, $T_f = 35\text{°C}$, $c_{\text{iron}} = 460 \text{ J kg}^{-1} \text{°C}^{-1}$, and $c_w = 4200 \text{ J kg}^{-1} \text{°C}^{-1}$. When the iron piece is dropped into water, it loses energy and water gains energy. Let the initial temperature of the iron piece be T.

Energy lost by iron piece $= m_{\text{iron}}c_{\text{iron}}(T - T_f)$
$= 0.1 \text{ kg} \times 460 \text{ J kg}^{-1} \text{°C}^{-1} (T - 35\text{°C})$
$= 46 \times (T - 35\text{°C}) \text{ J °C}^{-1}$.

Energy gained by water $= m_w c_w (T_f - T_i)$
$= 1 \text{ kg} \times 4200 \text{ J kg}^{-1} \text{°C}^{-1} \times (35\text{°C} - 29.5\text{°C})$
$= 23\,100$ J

From the law of conservation of energy
Heat lost = heat gained, or
$46\,(T - 35\text{°}) \text{ J °C}^{-1} = 23\,100$ J, or
$T = 537.2\text{°C}$.

Answer The initial temperature of the iron piece was 537.2°C.

Example 13.7 In an experiment on determination of specific heat capacity of glycerine, 1.2 kg of glycerine at a temperature of 60°C is mixed with 2.0 kg of water at 10°C. The final temperature of the mixture is 30°C. What is the specific heat capacity of the glycerine?

Solution $m_w = 2$ kg, $c_w = 4200 \text{ J kg}^{-1} \text{°C}^{-1}$ $m_g = 1.2$ kg, $T_i = 10\text{°C}$, $T_f = 30\text{°C}$ and $T = 60\text{°C}$, $c_g = ?$

Heat lost by glycerine $= m_g c_g (T - T_f)$
$= 1.2 \text{ kg } c_g (60\text{°C} - 30\text{°C})$
$= 36\, c_g \text{ kg °C}$.

Heat gained by water $= m_w c_w (T_f - T_i)$
$= 2 \text{ kg} \times 4200 \text{ J kg}^{-1} \text{°C}^{-1} (30\text{°C} - 10\text{°C})$
$= 168\,000$ J.

Heat lost = heat gained, or
$36\, c_g \text{ kg °C} = 168\,000$ J, or
$c_g = 4666.7 \text{ J kg}^{-1} \text{°C}^{-1}$.

Answer The specific heat capacity of glycerine is $4667 \text{ J kg}^{-1} \text{°C}^{-1}$.

Example 13.8 Find the amount of heat energy needed to melt 100 g of ice completely at 0°C.

Solution When ice melts and is converted to water at the same temperature, energy must be supplied from outside.

Energy supplied = mass of ice × specific latent heat of fusion

$$= 0.1\ \text{kg} \times 336 \times 10^3\ \text{J kg}^{-1}$$
$$= 3.36 \times 10^4\ \text{J}.$$

Answer 3.36×10^4 J of heat energy must be supplied to melt 100 g of ice completely.

EXAMPLE 13.9 How much heat energy is required to convert 1 kg of ice at 0°C to steam at 100°C ?

Solution $m = 1$ kg, $T_i = 0°\text{C}$, $T_f = 100°\text{C}$, $l_f = 336 \times 10^3$ J kg^{-1}, $c = 4200$ J kg^{-1} °C^{-1} and $l_v = 2260 \times 10^3$ J kg^{-1}. Here energy is required first to melt ice, then to raise the temperature of water from 0°C to 100°C and finally to convert water at 100°C to steam at 100°C.

(i) Heat required to melt ice at 0°C
$= m \times l_f = 1\ \text{kg} \times 336 \times 10^3\ \text{J kg}^{-1} = 3.36 \times 10^5\ \text{J}$

(ii) Heat required to change the temperature of water from 0°C to 100°C
$= mc(T_f - T_i) = 1\ \text{kg} \times 4200\ \text{J kg}^{-1}\ °\text{C}^{-1} \times 100°\text{C}$
$= 4.2 \times 10^5$ J.

(iii) Heat required to convert water at 100°C to steam
$= ml_v = 1\ \text{kg} \times 2260 \times 10^3\ \text{J kg}^{-1} = 2.26 \times 10^6\ \text{J}$

Total heat energy required

$$= 3.36 \times 10^5\ \text{J} + 4.22 \times 10^5\ \text{J} + 2.26 \times 10^6\ \text{J}$$
$$= 3.018 \times 10^6\ \text{J}$$

Answer The heat energy required to convert 1 kg ice to steam is 3.018×10^6 J (718 000 cal).

EXAMPLE 13.10 When sweat evaporates from the skin, the temperature of the body decreases as the latent heat of vaporization is supplied by the body. Calculate the amount of sweat evaporated from the body of a 60.0 kg person to cool him by 1.00°C. The heat of vaporization of sweat is 1320 J kg^{-1}.

Solution $m = 60$ kg, $\Delta T = 1°\text{C}$, $l_v = 1320$ J kg^{-1} and $c = 3486$ J kg^{-1}. Let M be the amount of sweat evaporated to cool the body by 1°C.

Amount of heat withdrawn from the body when its temperature decreases by 1°C $= mc\,\Delta T$

$$= 60\ \text{kg} \times 3486\ \text{J kg}^{-1} \times 1°\text{C}$$
$$= 209\ 160\ \text{J}.$$

When the sweat evaporates, the heat energy needed for evaporation is drawn from the body. The heat energy required for evaporation of sweat of mass $M = Ml_v = 1320\ M$ J kg^{-1} Hence,

$$1320\ M\ \text{J kg}^{-1} = 209\ 160\ \text{J, or}$$
$$M = \frac{209\ 160\ \text{J}}{1320\ \text{J kg}^{-1}} = 158\ \text{kg}.$$

Answer The mass of sweat required is 158 kg!

EXAMPLE 13.11 In places where the temperature goes below 0°C, the release of heat energy by freezing water is utilized to prevent a drastic fall in the room temperature by people who cannot afford heating systems. Suppose that a room of volume 50 m^3 is to be kept at 4°C, when the water in a tub inside the room freezes completely. How much water does the tub contain?

Solution Volume of room = 50 m^3, mass of air inside the room = $50\ \text{m}^3 \times 1.29\ \text{kg m}^{-3}$ = 64.5 kg, $c_{air} = 1050$ J kg^{-1} °C^{-1}.

If no water is kept in the tub, the room temperature will keep on decreasing. In order to keep the room at 4°C heat energy must be supplied to the air inside the room. This energy can be supplied by the freezing water which releases energy in the form of latent heat. When water starts freezing the air temperature will rise from 0°C. Let the mass of the water in the tub be M.

Heat released by complete freezing of water of mass $M = Ml_f$.

Heat required to raise the air temperature from 0°C to 4°C $= m_{air}\, c_{air}\, \Delta T$

$$= 64.5\ \text{kg} \times 1050\ \text{J kg}^{-1}\ °\text{C}^{-1} \times 4°\text{C}$$
$$= 270\ 900\ \text{J}$$

Hence,

$$M \times 336 \times 10^3\ \text{J kg}^{-1} = 270\ 900\ \text{J, or}$$
$$M = \frac{270\ 900\ \text{J}}{336 \times 10^3\ \text{J kg}^{-1}} = 0.87\ \text{kg}$$

Answer The tub should contain 0.87 kg of water.

NOTE A somewhat similar procedure is adopted by farmers to save their crops from frost. They fill their fields at night with water. The heat released by the freezing water keeps the crop warm, thereby saving it from damage by frost.

PROBLEMS

(Wherever needed take the relevant value from tables)

13.1 What is the heat capacity of 10 kg of (i) iron, (ii) wood, and (iii) water?

13.2 2205 J of heat is required to raise the temperature of a 250 g block by 10°C. Find the specific heat capacity of the solid.

13.3 Normally a clinical thermometer contains about 1.5 g of mercury (it varies from 1 g to 2 g). On a day when the air temperature is 20°C, the thermometer reads 39°C when withdrawn from the body. How much heat energy has been supplied by the body to the thermometer? Assume that the glass takes negligible heat energy.

13.4 A copper ball falls to the ground and its temperature rises by 1.4°C. If one half of its kinetic energy is converted into heat energy on impact, calculate the height through which the ball has fallen.

13.5 In a waterfall, water falls from a height of 100 m. Assuming that the whole of the kinetic energy of the water at the bottom of the fall is converted into heat energy, calculate the difference in temperature of the water between the top and bottom of the fall? Assume that at the top of fall, the speed of the water is zero.

13.6 Various calculations and experimental work indicate that the average heat produced inside the human body, by burning the food, is about 8.400×10^{9} J per day for a person of mass 60 kg. What would be the increase in the body temperature per day if no part of the heat produced is lost to the surroundings (specific heat of body is 3486 J kg^{-1} °C^{-1})?

13.7 When a spacecraft enters the earth's atmosphere, its motion is opposed by the gases in the atmosphere. Due to this opposing force, the kinetic energy of the spacecraft is converted mostly into heat energy. As a consequence, its temperature increases tremendously. A spacecraft is therefore provided with special heat shields which prevent damage to the interior. Suppose a spacecraft made of aluminium enters the earth's atmosphere at a speed of 800 ms^{-1} and is slowed down to 40 ms^{-1}. Find the rise in temperature of the spacecraft.

13.8 A meteorite of mass 10 kg travelling at a speed of 200 ms^{-1} enters the earth's atmosphere. Its speed is reduced to 50 ms^{-1} by the frictional forces produced by the atmospheric gases. (i) How much heat energy is produced? (ii) What is the specific heat capacity of the meteorite if the rise in temperature is 100°C?

13.9 Calculate the amount of heat energy lost by a 5.000 kg piece of wood when it cools from 60°C to 5°C.

13.10 63 000 J of heat energy is supplied to 5.000 kg of ice to change its temperature from −9°C to −3°C. Determine the specific heat capacity of the ice.

13.11 What is the power of the heating element of an electric kettle which heats 2000 g of water from 30.0°C to 79°C in 9.80 min?

13.12 Calculate the rise in the temperature of 10.00 kg of water which is heated by a 1400 W heater for 10.00 minutes.

13.13 Determine the temperature of the mixture when 150 g of water at 60.0°C is mixed with 450 g of water at 10.0°C.

13.14 How much water at 20°C will cool 4.00 kg of glass from 100°C to 40°C? The specific heat capacity of glass is 840 J kg^{-1} °C^{-1}.

13.15 How much ethyl alcohol at temperature 70°C should be added to 100 g of ethyl alcohol at temperature 0°C to raise its temperature to 50°C?

13.16 280 g of turpentine at 60°C is mixed with 2100 g of ethyl alchol at 30°C. If the temperature of the mixture is 35°C, determine the specific heat capacity of the turpentine.

13.17 How much heat energy will be liberated by freezing 5 kg of lead?

13.18 How much energy must be removed from 2.5 kg of water at 20°C in order to just freeze it?

13.19 A vacuum flask contains 0.36 kg of ice and no water. Since the body of the flask is not a perfect insulator, some heat enters the flask and melts the ice. Suppose 3.36 J of heat enters the flask per second. How long does it take to melt the ice completely?

13.20 How much ice at 0°C will be melted by 100 g of steam?

13.21 How much heat energy is needed to melt 20 g ice at 0°C and then to raise the temperature of the water to 10°C?

13.22 Calculate the excess energy possessed by 1.5 kg of steam at 100°C than by water at the same temperature.

13.23 How much energy will be given off by 0.5 kg of steam if it is cooled to water at a temperature of 70°C?

13.24 When 210 g of water at 19°C is added to 34 g of ice at 0°C, the final temperature of the mixture becomes 5°C. Determine the specific latent heat of fusion.

13.25 How much ice is needed to cool 3.36 kg water from 60°C to 30°C? Ice is not mixed with water.

13.26 What is the water equivalent of a copper calorimeter of mass 42 g?

13.27 What is the mass of an aluminium calorimeter, if the water equivalent is 2.3 g?

13.28 Find the specific heat capacity of the material of a calorimeter which has a mass of 100 g and water equivalent of 25 g.

13.29 A copper calorimeter of mass 500 g has 50 g of ice. 50 g of boiled water at 100°C is added to it. Find the final temperature of the mixture.

13.30 When 10.0 g of steam at 100°C is passed through 145 g of water at 20.0°C, the temperature of the water rises to 60.0°C. Calculate the latent heat of vaporisation of water.

13.31 Determine the specific heat capacity of ether from the following observations: mass of copper calorimeter = 36.0 g, mass of calorimeter + ether = 108 g, initial temperature of ether = 25.0°C, mass of iron piece = 18.0 g, temperature of the iron piece = 145°C, and final temperature of ether = 31.3°C.

13.32 A metal piece of mass 40.0 g is heated on a flame till its temperature becomes equal to that of the flame and then it is quickly transferred to a calorimeter of mass 90.0 g containing 180 g of water at 17.0°C. If the temperature of water rises to 41°C, determine the temperature of the flame. Given that the specific heat capacity of metal and calorimeter are 540 J kg^{-1} $°C^{-1}$ and 450 J kg^{-1} $°C^{-1}$, respectively.

13.33 Determine the amount of heat energy given out when (i) 3.0 kg of steam condenses to water and (ii) 3.2 kg of water is converted to ice, without any change in temperature.

13.34 How much heat energy is required to convert (i) 10 kg of ice to water and (ii) 10 kg of water to steam at constant temperature?

13.35 In Delhi the average solar energy received per day is about 2.85×10^7 J m^{-1} s^{-8}. Calculate the rise in temperature of 100 litre water if it absorbs this much of energy. (In the available solar water heaters in the market, the rise in temperature is about 30°C.)

14 Reflection of Light

We now turn to the study of one of the first branches of physics which underwent substantial development during the 20th century. In the beginning it seems that there is little connection between light and the physics which we have studied so far. However, this impression, as we will see, is not tenable. Light has many things common with other branches of physics.

Probably of all the human senses, the most important is sight. One of our most important contacts with the world around is therefore through light. Most of the knowledge about the world is derived when light falls on our *eyes* and on *optical instruments*. Light is the most important tool available to mankind for the investigation of the macroscopic world—solar system, stars, glaxies etc., as well as the miroscopic world—atoms, molecules, etc.

14.1 BASIC CONCEPTS

Light is complicated in nature. To study it, we have to simplify its behaviour. Although light travels as a transverse wave and sometimes behaves as a particle, most of the simple observable phenomena can be explained by assuming that light travels in straight lines. This approach is called *geometrical optics* (D. 14.3).

TABLE 14.1 The range of wave lengths associated with light.

Colour	*Wave length* (10^{-7} m)
Red	6.47-7.0
Orange	5.85-6.47
Yellow	5.75-5.85
Green	4.912-5.75
Blue	4.24-4.912
Violet	4.00-4.240

D. 14.1 Light A form of energy or the agency that causes a visual sensation when it falls on the retina of the eye.

NOTES (i) The chemical effects produced on the photographic plate, photosynthesis in plants, photoelectric effect (the ejection of electrons from some metals when light falls on them) are some effects which demonstrate that *light is a form of energy.*

(ii) Light does not require a medium to travel.

(iii) Light forms a narrow section of the electromagnetic spectrum. The wavelength of the visible portion of the spectrum is 7×10^{-7} m to 4×10^{-7} m.

(iv) In vacuum, light has a velocity of 3×10^8 ms^{-1}. In all other mediums its velocity is less than 3×10^8 ms^{-1}.

D. 14.2 Optics A branch of physics concerned with the study of light, its production, propagation, measurement and properties.

D. 14.3 Geometrical Optics A branch of optics where some of the observable effects of light are explained on the assumption that light travels in straight lines.

NOTE In geometrical optics mainly reflection (14.2) and refraction (D. 16.3) are discussed.

D. 14.4 Ray of Light A simple representation of the straight line path of light.

PICTORIAL REPRESENTATION A straight line with an arrowhead at its mid-point indicating the direction of propagation of light, Fig. 14.1.

FIG. 14.1 A ray of light. The light travels in the direction of the arrow.

D. 14.5 Beam of Light A collection of light rays.

EXAMPLES See Fig. 14.2.

PICTORIAL REPRESENTATION More than one straight line with arrowheads at their mid points indicating the direction of propagation.

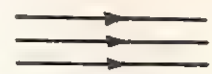
TYPES OF BEAMS OF LIGHT

(*i*) *Parallel beam of light* A beam of light in which rays of light are parallel to each other, Fig. 14.2(a).

(*ii*) *Divergent beam of light* A beam of light in which rays of light are travelling away from a point, Fig. 14.2(b).

(*iii*) *Convergent beam of light* A beam of light in which rays of light are travelling towards a point, Fig. 14.2(c).

(*iv*) *Pencil of light* A narrow beam of light.



(a) Parallel

(b) Divergent

(c) Convergent

FIG. 14.2 A beam of light is a collection of light rays.

D. 14.6 Optical Medium (*or, simply, Medium*) A substance through which light can travel.

TYPE OF MEDIUMS

(*i*) *Opaque medium* A substance which does not allow light falling on it to pass through.

EXAMPLES Metals, wood, concrete.

(*ii*) *Translucent medium* A substance which allows only a part of the light falling on it to pass through, but through which one cannot see.

EXAMPLES Oil paper, ground glass, some types of plastic sheets.

(*iii*) *Transparent medium* A substance which allows a major portion of light falling on it to pass through.

EXAMPLES Most of the glasses, almost all the gases, colourless liquids, etc.

NOTES (i) In nature there is no material substance through which all the light incident on it can pass (such a substance would be invisible to the eye since it would not reflect any light.)

(ii) The nature of a substance (opaque, translucent or transparent) depends on the wavelength of light. A substance may be transparent for light of a particular wavelength and opaque for light of other wavelengths.

D. 14.7 Luminuous Body A body which emits light of its own.

EXAMPLES Stars, sun, burning fuel, electric bulb, some of the living creatures like glowworm or fire fly.

D. 14.8 Nonluminous Body A body which does not emit its own light.

EXAMPLES All solids, liquids and gases at room temperature.

NOTE Nonluminous bodies can only be seen in the presence of a luminous body. Light from a luminous body first falls on a nonluminous body. When the reflected light (D. 14.9) from the nonluminous body enters our eyes, only then do we become aware of the presence of the nonluminous body.

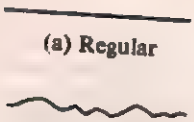


FIG. 14.3 Two types of reflecting surfaces.

14.2 PHENOMENON OF REFLECTION

Reflection is one of the most important natural phenomena. The human eye will be more or less useless without the phenomenon of reflection, which enables us to see the multitude of nonluminous objects around us.

D. 14.9 Reflection The phenomenon in which some or all of the light which falls on a surface is thrown back by the surface.

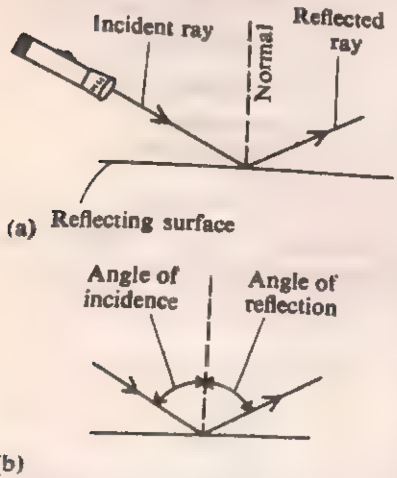


FIG. 14.4 The incident ray is the light ray travelling towards the reflecting surface and the reflected ray goes away from the reflecting surface.

D. 14.10 Reflecting Surface A surface of a body which is capable of throwing back most of the light which falls upon it.

NOTES (i) All surfaces, which do not appear black in colour, reflect some of the light which falls upon them. Black surfaces appear to be black in colour because they reflect none of the light falling upon them.

(ii) In physics, the surfaces which are considered to be useful reflecting surfaces are those which throw back most or all of the light falling upon them. Here, we shall use the term 'reflecting surface' to mean this.

TYPES OF REFLECTING SURFACES There are two basic types of reflecting surfaces.

(*i*) *Regular reflecting surface* One which is smooth or even-textured, Fig. 14.3(a).

EXAMPLES Mirror, unsilvered glass, smooth metallic surface.

(*ii*) *Irregular reflecting surface* One which is not smooth, Fig. 14.3(b).

EXAMPLE An uneven surface.

NOTE If we wish to see a surface, then it must be an irregular reflecting surface otherwise we will only see the image of the object and not the surface. The surface will be seen only when reflection from the surface is diffused. An unpolished glass surface can be seen in sunlight but in polished glass, the image of the sun will be visible.

D. 14.11 Incident Ray A ray of light travelling towards and falling upon a reflecting surface, Fig. 14.4.

D. 14.12 Point of Incidence A point on the reflecting surface where the incident ray meets the reflecting surface, Fig. 14.4.

D. 14.13 Reflected Ray A ray of light travelling away from a reflecting surface after reflection, in the same medium which contains the incident ray, Fig. 14.4.

D. 14.14 Normal to the Reflecting Surface (*or, simply, Normal*) The straight line perpendicular to the reflecting surface at the point of incidence, Fig. 14.4.

D. 14.15 Angle of Incidence A measure of the direction of the incident ray with respect to the reflecting surface.

WRITTEN REPRESENTATION i, θ_i

SPECIFICATION The angle between incident ray and the normal at the point of incidence. Measured in degrees (°), minutes (′) and seconds (″) of an arc.

D. 14.16 Angle of Reflection A measure of the direction of the reflected ray with respect to the reflecting surface.

WRITTEN REPRESENTATION r, θ_r

SPECIFICATION The angle between reflected ray and the normal at the point of incidence. Measured in degrees (°), minutes (′) and seconds (″) of an arc.

LAWS OF REFLECTION The incident and reflected rays obey certain laws. These laws are simple and are always obeyed irrespective of the nature of the surface.

Law 16: First Law of Reflection

The incident ray, the reflected ray and the normal to the reflecting surface at the point of incidence all lie in the same plane.

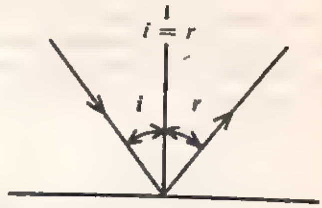


FIG. 14.5 Laws of reflection. The angle of reflection always equals the angle of incidence.

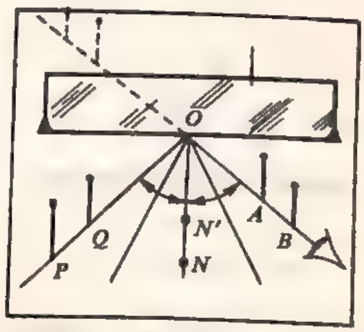


FIG. 14.6 Verification of law of reflection. Place a mirror on a big white paper. (a) Put two pins N, N' on the white paper such that when the eye is placed behind NN', these pins and their images are in one line. Draw a line joining NN' meeting the mirror at point O. Line ONN' is the normal to the mirror. (b) Draw a line PQO at an angle of 40° to the normal. Place two pins P, Q on this line. See the image of pins P, Q and place two pins such that the images of P, Q and pins A, B are in one line. Measure angles PON and NOB. Show that $\angle PON = \angle NOB$.

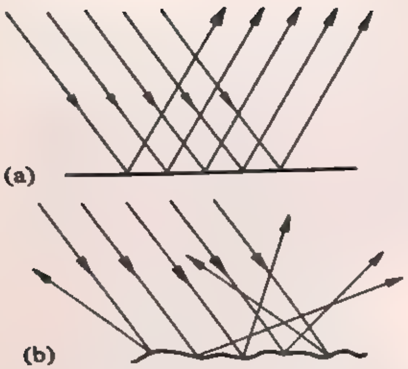


FIG. 14.7 (a) Regular and (b) diffuse reflection. In regular reflection the reflected beam remains a parallel beam while in diffuse reflection it does not remain so.

LAW 17: SECOND LAW OF REFLECTION

The angle of incidence is equal to the angle of reflection.

MATHEMATICAL EXPRESSION

$$r = i \qquad (E.\ 14.1)$$

D. 14.17 Regular Reflection The reflection occurring at a regular surface.

EXAMPLE See Fig. 14.7(a).

NOTE When a beam of parallel rays falls on a regular surface, the angle of incidence is the same for every ray. The angle of reflection is, therefore, also the same for every ray. The reflected beam will consist of parallel rays.

D. 14.18 Diffuse Reflection The reflection occurring at an irregular surface.

EXAMPLE See Fig. 14.7(b).

NOTES (i) For a parallel beam of light, the angle of incidence is not the same for every incident ray because of the irregularities in the reflecting surface. The reflected beam, therefore, does not remain a parallel beam of light.

(ii) This type of reflection is difficult to study.

(iii) The laws of reflection are always valid no matter what happens.

(iv) Diffuse reflection is more important than regular reflection in day to day life. See note after irregular reflecting surface, D. 14.10.

14.3 PLANE MIRROR AND ITS APPLICATIONS

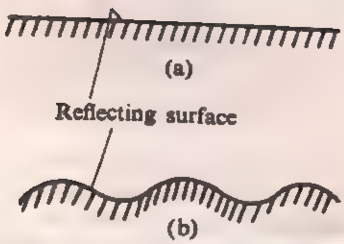


FIG. 14.8 Pictorial representation of a mirror. The side with fine oblique lines does not permit light to pass through.

D. 14.19 Mirror A regular surface which can efficiently reflect most of the light falling on it.

EXAMPLES Looking glass, viewing glass, etc.

PICTORIAL REPRESENTATION A mirror is pictorially represented by a thick line marked with fine oblique lines on the side which does not allow light to pass through, Fig. 14.8.

NOTES (i) Mirrors are usually produced by polishing a metallic surface or by depositing a layer of 'shining metal' on the back of a regular glass plate.

(ii) Mirrors can have various shapes, sizes and curvatures [e.g. plane mirrors (D. 14.20), spherical mirrors (D. 15.1), paraboloidal mirrors (D. 15.4), distorting mirrors (seen very often in fairs) etc.]

(iii) An ordinary looking glass reflects about 90% of the light incident on it. Mirrors specially prepared by depositing a fine film of silver over a metal surface reflect approximately 99% of the light incident on them.

D. 14.20 Plane Mirror A mirror whose reflecting surface lies in one plane; a flat mirror.

EXAMPLES The mirrors used at home for shaving, dressing, makeup etc.

PICTORIAL REPRESENTATION See Fig. 14.9.

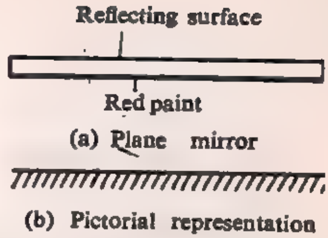


FIG. 14.9 Plane mirror. The reflecting surface lies in a plane. The reflecting material is coated on the other side of the surface and red paint is applied over it to prevent damage to the reflecting surface.

D. 14.21 Object The physical or geometrical point or set of points from which light is taken to be incident on the mirror.

EXAMPLES See Fig. 14.10.

PICTORIAL REPRESENTATION By a point or a solid line.

D. 14.22 Image The point or set of points at which the reflected rays from a mirror actually meet or seem to meet.

EXAMPLES See Fig. 14.11.

PICTORIAL REPRESENTATION By a point or a dotted line.

TYPES OF IMAGES There are two types of images.

(*i*) *Real image* The point or set of points at which the reflected rays actually converge or meet. It can be obtained on a screen and can also be seen.

(*ii*) *Virtual image* The point or set of points from which reflected rays appear to diverge. It cannot be obtained on a screen but can be seen.

NOTES (i) Normally the image formed by the plane mirror is *virtual* because the incident beam of light is *divergent*.

(ii) A real image is always formed in front of the mirror and the virtual image is always formed behind the mirror, where a screen cannot be placed.

(iii) A plane mirror forms a *real image* when a *convergent beam* of light falls on it. See Fig. 14.11(b).

FIG. 14.10 (a) Object. The source of incident light rays for a mirror. (b) An image is the point or set of points to which rays converge after reflection.

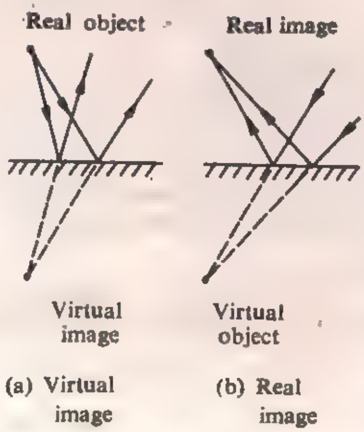


FIG. 14.11 Formation of virtual and real image by a plane mirror.

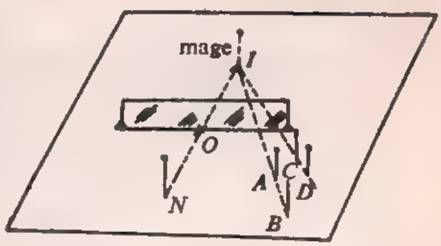


FIG. 14.12 Locating an image by geometric construction. Place two pins *A* and *B* in line with image *I*. Place two more pins *C* and *D* in a similar way at a different location. The point of intersection of lines *AB* and *CD*, which is behind the mirror, is the position of the image.

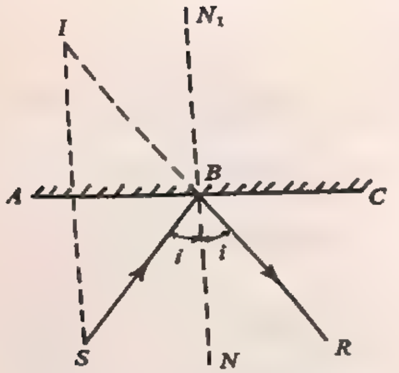


FIG. 14.13 Position of image. The image is as far behind the mirror as the object is in front of the mirror.

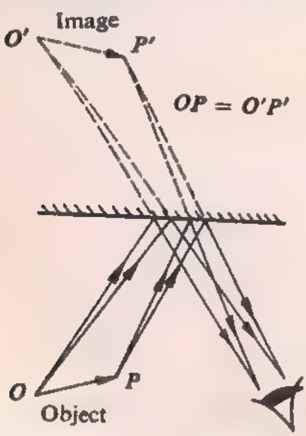


FIG. 14.14 Size of image. The image formed by a plane mirror is erect and is of the same size and shape as the object.

Characteristics of an Image Formed by a Plane Mirror

(*i*) *Construction of the image* See Fig. 14.12.

(*ii*) *Nature of image* Virtual as it is behind the mirror and hence cannot be obtained on the screen.

(*iii*) *Position of image : Analytical method* See Fig. 14.13.

(a) $\angle SBN = \angle NBR = i$ Law of reflection

(b) $\angle N_1BI = \angle NBR = i$

(c) $\angle ABS = \angle ABN - \angle SBN = 90° - i$

$\angle ABI = \angle ABN_1 - \angle N_1BI = 90° - i$, or

$\angle ABS = \angle ABI$ (*E.14.2*)

(d) $\angle ASB = \angle SBN = i$, $\angle AIB = \angle N_1BI = i$, or

$\angle ASB = \angle AIB$ (*E.14.3*)

(e) $\Delta ABI \equiv \Delta ASB$, E.14.2, E.14.3 and AB common.

Hence, $AS = AI$ (*E.14.4*)

$\angle IAB = \angle BAS = 180° - \angle AIB - \angle ABI$

$= 180° - i - (90° - i) = 90°$ (*E.14.5*)

The image is as far *behind* the mirror as the object is in front of it (E.14.4). The line joining the object and image meets the mirror at *right angles* (E.14.5).

(*iv*) *Size of image* Same size as that of object. See Fig. 14.14.

(*v*) *Lateral inversion* See Fig. 14.15.

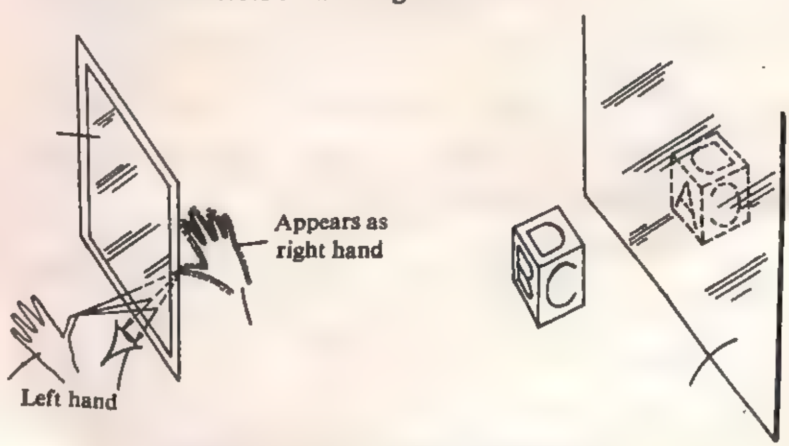


Fig. 14.15 Lateral inversion. The left and right of the object are interchanged in the image.

ROTATION OF PLANE MIRROR If a mirror is rotated by an angle α, the reflected ray is rotated by 2α. See Fig. 14.16.

Derivation See Fig. 14.16(b).

$$\angle SON = \angle NOR = i$$

When mirror is rotated by an angle α, th normal rotates by an equal angle, or $\angle NON' = \alpha$.

$$\angle SON' = \text{New angle of incidence} = i + \alpha = i'$$
$$\angle N'OR' = \text{New angle of reflection} = i + \alpha = r'$$
$$\angle NOR' = \angle N'OR' + \angle NON' = i + 2\alpha$$
$$\angle ROR' = \text{Angle by which reflected ray rotates}$$
$$= \angle NOR' - \angle NOR = i + 2\alpha - i$$
$$= 2\alpha.$$

MINIMUM SIZE OF A PLANE MIRROR REQUIRED TO SEE AN OBJECT

The length of the mirror should be half of the length of the object to be seen. See Fig. 14.17.

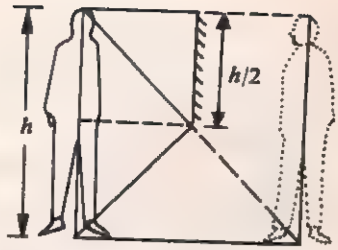


FIG. 14.17 To be able to see your full height in the mirror, the mirror should be half of your height.

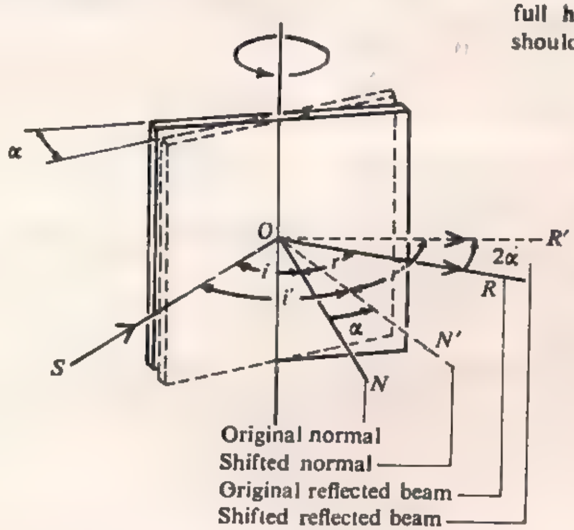


Fig. 14.16 When the mirror turns through α the reflected beam turns through 2α

SOLVED EXAMPLES

Example 14.1 A ray of light falls on a plane mirror. Determine the angle of reflection if the angle of incidence is (i) 0° (ii) 45° (iii) 90°.

Solution According to the second law of reflection, the angle of reflection is always equal to the angle of incidence.

(i) Since $i = 0°$, $r = 0°$. This is known as *normal incidence*. The incident ray retraces its own path after reflection.

(ii) Here $i = 45°$, r will also be 45°.

(iii) Since $i = 90°$, $r = 90°$. This is known as *grazing incidence*. The incident light remains undeviated.

Answer The angles of reflection for the three cases are 0°, 45° and 90°, respectively.

Example 14.2 A candle 5 cm long is placed 10 cm away from a plane mirror. Determine the position and size of the image.

Solution The image in the plane mirror is formed as far behind, as the object is in front of the mirror. Further, the image is of the same size. The image will, therefore, be 5 cm long. It will be 10 cm behind the mirror. The line joining the image and object will make an angle of 90° with the mirror.

Answer The image is 10 cm behind the mirror and is 5 cm long.

Example 14.3 A person 1.6 m tall wants to see his full image in a plane mirror. What should be the minimum height of the plane mirror? Does the distance of the person from the mirror affect the answer?

Solution The minimum height of the plane mirror should be half of the person's height. Thus the minimum height of the mirror should be 1.6 m/2 = 0.8 m. The distance of the person from the mirror does not change the answer.

Answer The minimum height of the mirror should be 0.8 m which is independent of the person's position in front of the mirror.

Example 14.4 A plane mirror is mounted on the back of a truck. The truck is moving with a speed of 5 ms^{-1}. How fast will the image of a man standing on the road behind the truck appear to move (i) with respect to the mirror and (ii) with respect to the man?

Solution In a plane mirror the image is as much behind the mirror as the object is in front of it. If the object moves a distance *y* away from the mirror the image will also move by an equal amount away from the mirror. In the present problem, the truck is moving at the rate of 5 ms^{-1} away from the man. Thus his image will also move at the rate of 5 ms^{-1} away from the mirror.

(i) The speed with which the image of the man appears to move with respect to mirror = 5 ms^{-1}.

(ii) The change in the distance between the man and his image per second = ch 14.3) of distance between man and mirror pe[illegible] + change of distance between mirror an 14 [illegible]mage per second = 5 m + 5 m = 10 m.

Speed of the image with respect to the man = change in distance between the man and his image per second = 10 ms^{-1}.

Answer The image of the man will move at a speed of (i) 5 ms^{-1} with respect to the mirror, and (ii) 10 ms^{-1} with respect to the man.

PROBLEMS

14.1 If the angle of reflection is (i) 10°, (ii) 40°, and (iii) 0°, what will be the angle of incidence?

14.2 The image of an object is 10 cm behind the mirror. How far is the object from the mirror?

14.3 The length of the image formed by a plane mirror is 4 cm. What is the length of the object?

14.4 A person standing 20 cm in front of a plane mirror moves 5 cm towards the mirror. In which direction will his image move and why? By how much will his image move?

14.5 When you stand before a mirror of height 0.6 m, you are just able to see your full image. What is your height?

14.6 An object approaches a plane mirror with a speed of 1 ms^{-1}. How fast does the image approach the mirror?

14.7 A mirror moves towards a tree with a speed of 2 ms^{-1}. What is the speed with which the image of the tree approaches the tree?

14.8 The image of an object appears to move away from the object with a speed of 8 ms^{-1}. Determine the speed with which the mirror is moving if the object is stationary.

14.9 Determine the angle of rotation of a mirror if the reflected ray is rotated by 40°.

15 Reflection at Curved Surfaces

Now we will turn to the study of another kind of mirrors—curved mirrors. These are completely different in action as compared to the plane mirrors, although the laws of reflection are valid for these mirrors as well. The difference in behaviour arises due to the fact that normals at two adjacent points on the curved mirror are not parallel. Curved mirrors have a large number of scientific and practical applications—in telescopes, torches, search lights, shaving and rear-view mirrors, and in medical sciences.

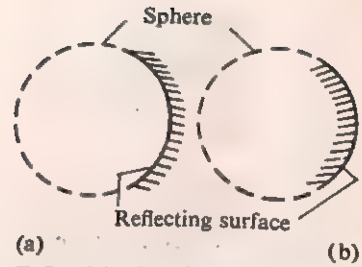


FIG. 15.1 A spherical mirror is a part of a hollow sphere. (a) Concave mirror—the inner surface of the sphere is the reflecting surface. (b) Convex mirror—the outer surface of the sphere is the reflecting surface.

15.1 TYPES OF CURVED MIRRORS

Many types of curved mirrors can be constructed. The two most important are the spherical and the paraboloid mirrors which have numerous applications in physics, technology, industry and daily life.

D.15.1 Spherical Mirrors A curved mirror whose reflecting surface geometrically forms a portion of the surface of a hollow sphere.

EXAMPLES Shaving mirrors, rear-view mirrors in vehicles, Fig. 15.2.

PICTORIAL REPRESENTATION An arc of a circle with oblique lines, to indicate the non-reflecting surface, Fig. 15.1.

LIMITATIONS These cannot produce a sharp image (D.15.14).

NOTE A spherical mirror may be either concave (D.15.2) or convex (D.15.3).

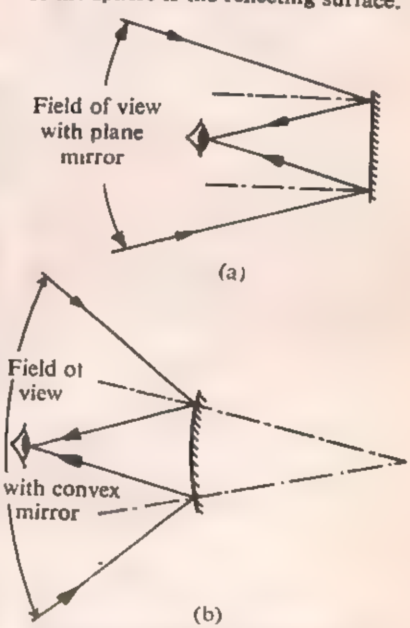


FIG. 15.2 Convex mirrors are used in vehicles because the field of view is much wider than in a plane mirror.

D.15.2 Concave Mirror A spherical mirror which curves 'inward' having a layer of reflecting material deposited on the 'outer' surface of the geometrical sphere of which the mirror is a part. The inner surface acts as the reflecting surface.

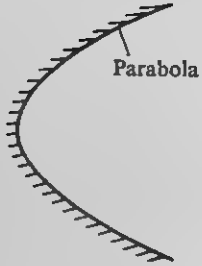


FIG. 15.3 A parabolic mirror is a part of a hollow paraboloid. It is usually concave in application.

FIG. 15.4 The pole is the central point of a curved mirror.

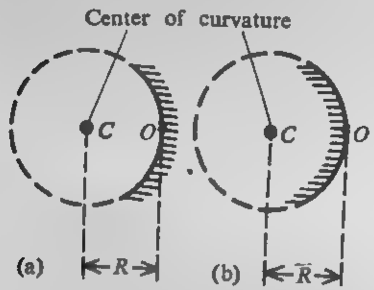


FIG. 15.5 The centre of curvature of a spherical mirror is the centre of the generating sphere and the radius of curvature is the distance between the centre of curvature and the pole. This is equal to the radius of the generating sphere.

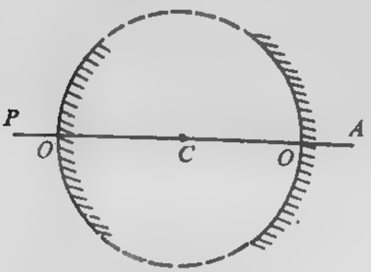


FIG. 15.6 The principal axis is the line which joins the pole to the centre of curvature. It is usually marked as *PA*.

EXAMPLES Shaving mirrors, mirrors used by doctors and dentists.

PICTORIAL REPRESENTATION See Fig. 15.1(a).

D.15.3 Convex Mirror A spherical mirror which curves 'outward' having a layer of reflecting material deposited on the 'inner' surface of the geometrical sphere of which the mirror is a part. The outer surface acts as the reflecting surface.

EXAMPLES Rear-view mirrors in vehicles, Fig. 15.2.

PICTORIAL REPRESENTATION See Fig. 15.1(b).

NOTE It is a common practice to deposit the reflecting material on that face of glass which does not receive the light itself. However, in many scientific applications it is the front surface which is coated with the reflecting material.

D.15.4 Paraboloidal Mirror A curved mirror whose reflecting surface geometrically forms a portion of the surface of a hollow paraboloid.

EXAMPLES Reflectors in search lights, torches, car head lights, electric heaters.

PICTORIAL REPRESENTATION A section of a parabola with oblique lines to indicate the non-reflecting surface, Fig. 15.3.

NOTE A paraboloidal mirror focuses an incident beam of light much more sharply than a spherical mirror.

15.2 CHARACTERISTICS OF SPHERICAL MIRRORS

Among curved mirrors, spherical mirrors are the easiest to understand and use. Several new concepts are involved in the study of the characteristics of spherical mirrors. Similar concepts are used in the study of paraboloidal and other curved mirrors.

D.15.5 Pole The centre of the spherical mirror.

PICTORIAL REPRESENTATION A point marked at the centre of the mirror; labelled as *O*. See Fig. 15.4.

D.15.6 Centre of Curvature The geometrical centre of the sphere of which the mirror is a part.

PICTORIAL REPRESENTATION A point marked on a diagram, which can be used as a centre for drawing the arc representing the mirrors; labelled as *C*. See Fig. 15.5.

NOTE The centre of curvature of a plane mirror is at infinity.

D.15.7 Principal Axis The straight line joining the pole with the centre of curvature.

PICTORIAL REPRESENTATION A straight line drawn from the pole of the mirror to the centre of curvature and extended beyond; usually marked *PA*. See Fig. 15.6.

D.15.8 Focal Point (*or, simply, Focus*) The point at which all the rays, which are parallel to the principal axis during incidence, physically or geometrically converge after reflection by a mirror. See Fig. 15.7.

PICTORIAL REPRESENTATION A point marked on the principal axis indicating the position of the focus; labelled F.

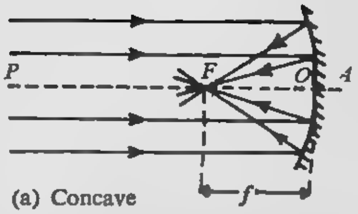
NOTES (i) The focal point is the image of the object at infinity.

(ii) In a concave mirror, the focal point can be obtained on the screen (*real point*) as it is in front of the mirror.

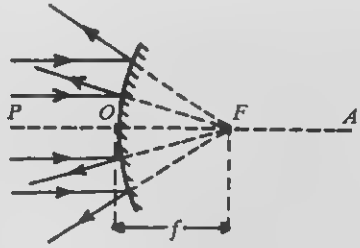
(iii) In a convex mirror, the focal point cannot be obtained on the screen (*virtual point*) as it is behind the mirror where the screen cannot receive any light.

(iv) The focus lies midway between the centre of curvature and the pole. See E. 15.1.

(v) In common usage, the word focus is used in another sense as well. When a sharp image of the object is obtained on the screen we say that the image is in focus.



(a) Concave



(b) Convex

FIG. 15.7 The focus is a point where parallel rays after reflection from a curved mirror will converge or appear to converge. (a) In a concave mirror it is a real point. (b) In a convex mirror it is a virtual point. The focal length is the distance between the focus and the pole.

D.15.9 Focal Length Fig. 15.7.

TYPE OF QUANTITY Scalar, with a sign (D.15.17).

WRITTEN REPRESENTATION f

SPECIFICATION The distance between the pole and the focus of a mirror. Measured in metre (m).

NOTE By convention, focal length of a concave mirror is *negative* and that of a convex mirror is *positive*.

D.15.10 Radius of Curvature Fig. 15.5.

TYPE OF QUANTITY Scalar, with a sign (D.15.17).

WRITTEN REPRESENTATION R

SPECIFICATION The distance between the pole and the centre of curvature of a mirror. Measured in metre (m).

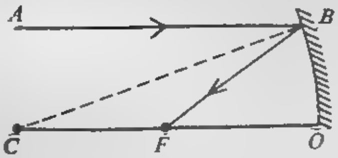
NOTES (i) The radius of curvature of a plane mirror is *infinite*.

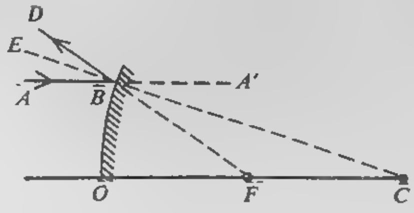
(ii) By convention, radius of curvature of a concave mirror is *negative* and that of a convex mirror is *positive*.

RELATION BETWEEN FOCAL LENGTH AND RADIUS OF CURVATURE

TABLE 15.1 Relation between f and R.

For concave mirror — *For convex mirror*





1. $\angle ABC = \angle CBF$ — $\angle ABE = \angle EBD$ Law of reflection

2. $\angle ABC = \angle BCF$ Alternate angles	$\angle ABE = \angle CBA'$ Opposite angles $= \angle BCF$ Alternate angles
3.	$\angle EBD = \angle CBF$ Opposite angles
4. From steps 1 and 2 $\angle BCF = \angle CBF$	From steps 1, 2 and 3 $\angle BCF = \angle CBF$

5. In a triangle, sides opposite to the equal angles are equal.

$FC = BF$ $\qquad\qquad$ $FC = BF$

6. If R is small and B is not far away from the pole.

$BF = OF$ $\qquad\qquad$ $BF = OF$

7. From steps 5 and 6

$$R = OC = OF + FC = 2OF = 2f. \qquad (E.15.1)$$

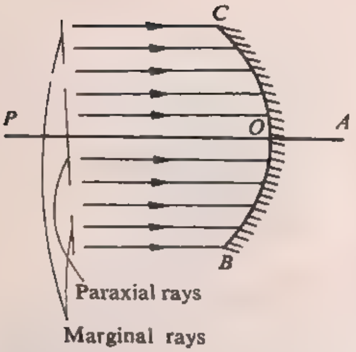


FIG. 15.8 Aperture, paraxial and marginal rays.

D.15.11 Aperture The width CB (Fig. 15.8) of the curved mirror or the part of a mirror through which light is allowed to reflect.

D.15.12 Paraxial Rays The rays which are close to the principal axis. For these rays, the angle of incidence is small, Fig. 15.8.

D.15.13 Marginal Rays The rays which are away from the principal axis. For these rays, the angle of incidence is large, Fig. 15.8.

D.15.14 Spherical Aberration The phenomenon in which all the parallel incident rays of the same colour after reflection from the spherical mirror do not pass through the focus, Fig. 15.9(a).

NOTES (i) The focus is then *no longer a point* but a small region.

(ii) A beam of light originating from an object placed at the focus of a spherical mirror, after reflection from the spherical mirror, will not become a *parallel beam* of light because of the spherical aberration.

(iii) In *parabolic mirrors* there is no spherical aberration, Fig 15.9(b). Hence in all the scientific applications where sharp images are required, a parabolic mirror is used.

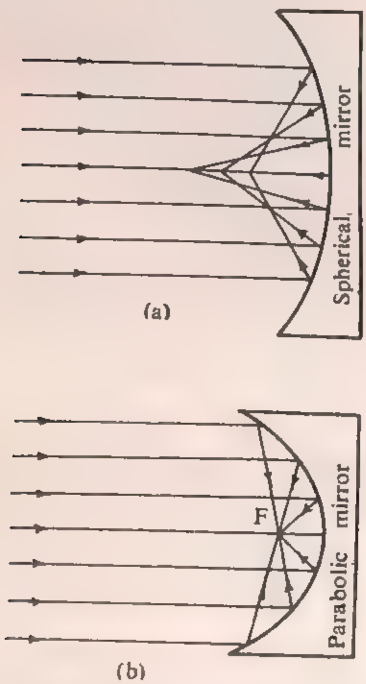


FIG. 15.9 Spherical abberation. It arises because the focal length of the paraxial and marginal rays are different. A parabolic mirror does not have this error.

15.3 WORKING PRINCIPLES

The concepts and the information provided by the preceding sections are all used when working with spherical mirrors either theoretically or experimentally. They have to be supplemented with the following principles and additional concepts.

D.15.15 Object Distance A measure of the position of the object with respect to a mirror.

TYPE OF QUANTITY Scalar, with a sign.

WRITTEN REPRESENTATION u

SPECIFICATION The distance of the base of the object on the principal axis from the pole of a mirror. Measured in metre (m), Fig.15.10.

D.15.16 Image Distance A measure of the position of the image with respect to the mirror.

TYPE OF QUANTITY Scalar, with a sign.

WRITTEN REPRESENTATION v

SPECIFICATION The distance from the base of the image on the principal axis to the pole of a mirror. Measured in metre (m), Fig. 15.10.

CONSTRUCTION OF THE IMAGE See Fig. 15.11.

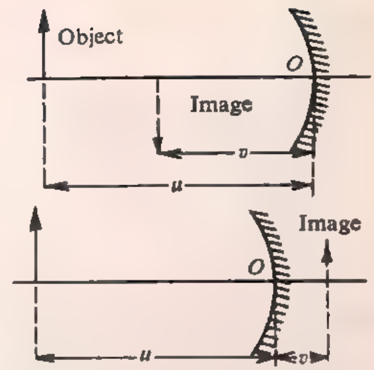
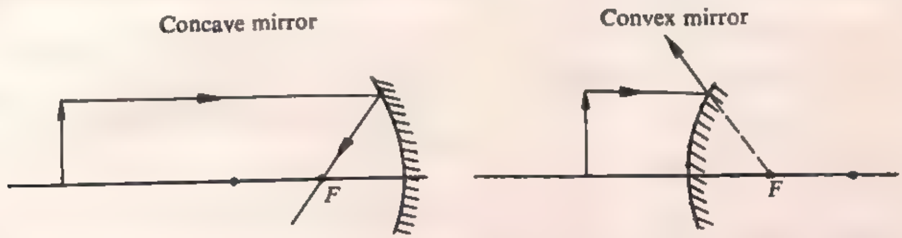
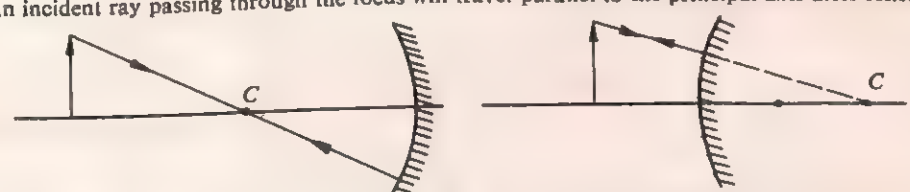


FIG. 15.10 The object distance u, and the image distance v. In a concave mirror, for a real image, both are negative while for a virtual image, u is negative and v positive. For a convex mirror u is negative and v positive.

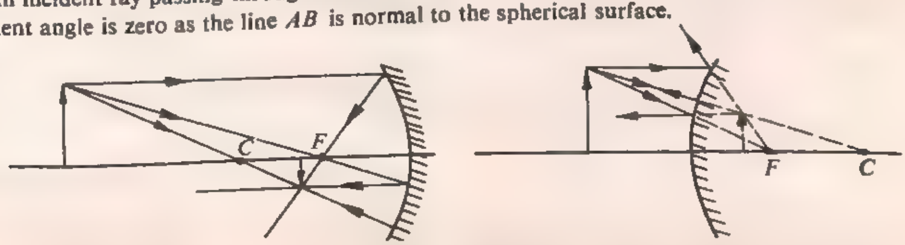


(a) *Ray* 1 : An incident ray parallel to the principal axis passes through the focus after reflection (property of focus).

(b) *Ray* 2 : An incident ray passing through the focus will travel parallel to the principal axis after reflection.



(c) *Ray* 3 : An incident ray passing through the centre of curvature will retrace its path after reflection. For this ray, the incident angle is zero as the line AB is normal to the spherical surface.



(d)

FIG. 15.11 The three special rays used in determining geometrically the position of the image.

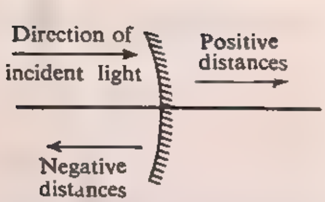


FIG. 15.12 Sign convention. If the object is always placed to the left of the mirror and the pole is taken as the origin of the coordinate system, then the sign convention of Table 15.2 is the same as the ***new coordinate sign convention.***

TABLE 15.2 The sign convention.

(i) All the distances are measured from the pole of the mirror.
(ii) Distances measured in the direction of the incident light ray are positive.
(iii) Distances measured in the direction opposite to the incident ray direction are negative.
(iv) Distances measured above the principal axis are positive.
(v) Distances measured below the principal axis are negative.

DISTINCTION BETWEEN PLANE, CONCAVE AND CONVEX MIRRORS

Take a needle and bring it towards the given mirror from a large distance. Note the change in the size of the image. The following cases arise.

Case I The size of the image *remains the same* as that of the needle whatever may be the position of the needle. The mirror is *plane.*

Case II The size of the image is *always less* than that of the needle no matter what the position of the needle. The mirror is *convex.*

Case III The size of the image *depends* on the position of the needle. It is smaller, bigger, and sometimes equal to the needle size depending upon the needle distance. The mirror is *concave.*

D.15.17 Sign Convention A convention for specifying various distances from the mirror surfaces involved in the quantitative study of reflection from the spherical mirror. See Fig. 15.12 and Table 15.2.

NOTE There is another convention still used by several authors. In this convention all the real image distances are positive and all the virtual image distances are negative. The object distance is always positive.

D.15.18 Mirror Formula A relation between focal length, object distance and image distance used in the quantitative study of image formation.

DERIVATION See Fig. 15.13.

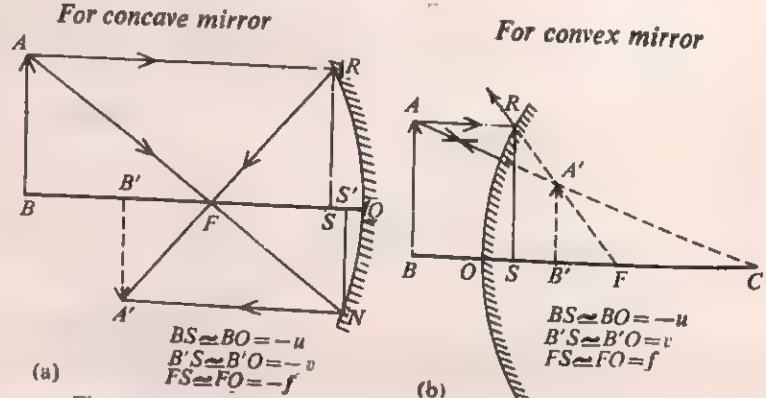


Fig. 15.13 Diagram for derivation of mirror formula. As AR is close to the principal axis, S will also be very close to O. Therefore S can be taken as the pole.

1. $\triangle ABF$ is similar to $\triangle FS'N$. $\triangle ABC$ is similar to $\triangle A'B'C$.

$$\frac{AB}{S'N} = \frac{BF}{S'F} \qquad \frac{AB}{A'B'} = \frac{BC}{B'C} \qquad (E.15.2)$$

2. $\Delta A'B'F$ is similar to ΔRSF.	$\Delta A'B'F$ is similar to ΔRSF.
$\dfrac{A'B'}{RS} = \dfrac{B'F}{SF}$	$\dfrac{A'B'}{RS} = \dfrac{B'F}{SF}$ (E.15.3)
3. $RS = AB$ ...(a) $S'N = A'B'$ ...(b)	$RS = AB$ (E.15.4)
4. Combine E.15.4(a) and E.15.3.	Combine E.15.4 and E.15.3.
$\dfrac{A'B'}{AB} = \dfrac{B'F}{SF}$ ...(a)	$\dfrac{A'B'}{AB} = \dfrac{B'F}{SF}$ (E.15.5)
Combine E.15.4 (b) and E.15.2.	
$\dfrac{AB}{A'B'} = \dfrac{BF}{S'F}$ ...(b)	
5. Combine E.15.5(a) and E.15.5(b).	Combine E.15.5 and E.15.2.
$S'F \times SF = BF \times B'F$	$B'C \times SF = BC \times B'F$ (E.15.6)
6. Substitute the various values.	
$f^2 = (-u+f)(-v+f)$	$(+2f-v)(+f) = (+2f-u)(+f-v)$
7. Simplify.	
$uv = uf+vf$	$uv = uf+vf$ (E.15.7)
8. Divide E.15.7 by uvf.	
$\dfrac{1}{f} = \dfrac{1}{v}+\dfrac{1}{u}$	$\dfrac{1}{f} = \dfrac{1}{v}+\dfrac{1}{u}$ (E.15.8)

D.15.19 Linear Magnification (*or, simply, Magnification*) A measure of the relative size of the image and object.

TYPE OF QUANTITY Scalar with a sign.

WRITTEN REPRESENTATION m

SPECIFICATION The ratio of the height of the image to the height of the object. No units.

MATHEMATICAL EXPRESSION As per specification

$$m = \frac{\text{height of image}}{\text{height of object}} = \frac{h_i}{h_o} \qquad (E.15.9)$$

DERIVATION See Fig. 15.14.

$\Delta A'B'F$ is similar to ΔRSF. Therefore

$$\frac{A'B'}{RS} = \frac{A'B'}{AB} = \frac{FB'}{FS}, \quad m = \frac{v}{f}-1 \qquad (E.15.10)$$

$$m = \frac{v}{u}, \text{ using E.15.8} \qquad (E.15.11)$$

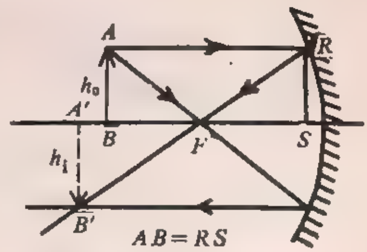
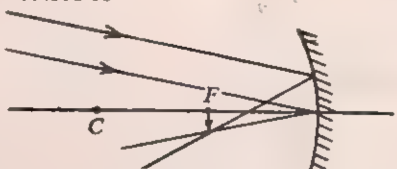
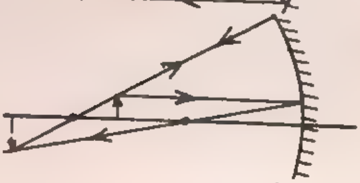
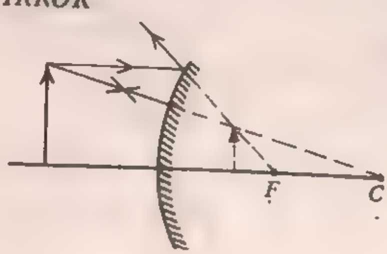


FIG. 15.14 Magnification is the ratio of image height to object height, $m=h_i/h_o$

TABLE 15.3 The object-image relationship for spherical mirrors.

Position of object		*Position of image*	*Nature of image*	*Comparative size of image*	*Example of application*
CONCAVE MIRROR					
At very large distance		At focus	Real, inverted	Almost a point	Reflecting astronomical telescope
Beyond C		Between F and C	Real, inverted	Smaller ($m < 1$)	Reflecting terrestrial telescope
At C		At C	Real, inverted	Same size ($m = 1$)	Mirror in a projector
Between F and C		Beyond C	Real, inverted	Larger ($m > 1$)	Flood light, projector, by doctors in examining ear and throat
At F		At infinity	—	—	Torch, search-light, head lamp of automobiles
Between pole and F		Behind the mirror	Virtual, upright	Large (m is negative $\|m\| > 1$)	Shaving mirror
CONVEX MIRROR					
Anywhere		Behind the mirror	Virtual, erect	Smaller	Rear view mirrors in vehicles, observation mirrors in stores (field of view is large and image is always upright)

NOTES (i) For real images m is positive and for virtual images it is negative.

(ii) $m = 0$ when image is formed at the focus.

(iii) For convex mirror m is either zero or negative. For concave mirror it can have any value, positive, negative or zero.

SOLVED EXAMPLES

EXAMPLE 15.1 What will be the focal length of a concave mirror of radius of curvature 0.6 m?

Solution $R = -0.6$ m. Negative sign shows that the mirror is concave.

$$f = \frac{R}{2} = -\frac{0.6m}{2} = -0.3 \text{ m}.$$

Answer The focal length of the concave mirror is 0.3 m.

(Alternative way of writing answer : The focal length of the mirror is -0.3 m. Here the negative sign will imply that the mirror is concave.)

EXAMPLE 15.2 An object is placed 20 cm away from a concave mirror. If the image is (i) 10 cm in front of the mirror, and (ii) 10 cm behind the mirror, determine the object and image distance in each case.

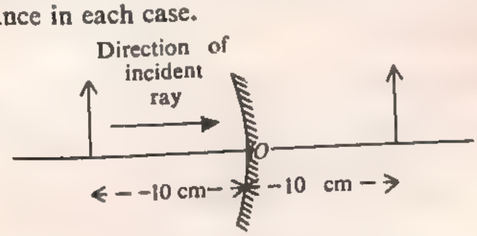


FIG. 15.15 Example 15.2.

Solution We will place the object on the left of the mirror because we want our sign convention to be the same as the coordinate convention. All the distances are to be measured from the pole O. Since the incident rays travel from the left to the right all the distances to the right of the pole, along the positive x-axis, are positive. All the distances to the left of the pole, along the negative x-axis, are negative.

(i) Here, the object and image are both along the negative x-axis. Hence,

$$u = -0.20 \text{ m and } v = -0.10 \text{ m}.$$

(ii) In this case, the object is along the negative x-axis and the image is along the positive x-axis. Hence,

$$u = -0.20 \text{ m and } v = 0.10 \text{ m}.$$

Answer The object and image distances in the two cases are (i) -0.20 m, -0.10 m and (ii) -0.20 m, 0.10 m.

EXAMPLE 15.3 An object 0.05 m high and at right angles to the principal axis is placed at a distance of 0.3 m in front of a concave mirror of radius of curvature 0.4 m. Determine the position and height of the image.

Graphical solution $R = 0.4$ m. Let the scale of Fig. 15.16 be 1 cm = 0.05 m.

(a) Draw a line PA. Take any point C as the centre of curvature.

(b) Draw an arc M_1M_2 of radius 8 cm with C as centre. M_1M_2 is then the concave mirror. The point F, half way between C and O is the focus. PA is the principal axis.

(c) Draw a line SQ, 1 cm long, perpendicular to the principal axis at a distance of 6 cm from O. This represents the object.

(d) Draw a line QQ_1 parallel to the principal

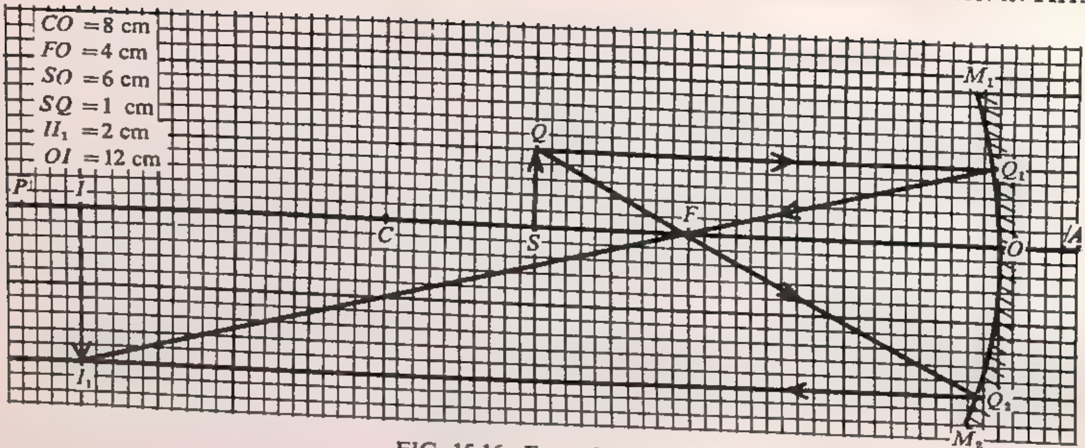


FIG. 15.16 Example 15.3.

axis. This incident ray after reflection from the concave mirror must pass through the focus F. Hence the ray Q_1FI_1 is the reflected ray.

(e) Draw a line QQ_2 passing through the focus F. This incident ray after reflection becomes parallel to the principal axis. Q_2I_1 is thus the other reflected ray.

(f) Two reflected rays Q_1I_1 and Q_2I_1 meet at I_1. Drop a perpendicular I_1I from I_1 on the principal axis. II_1 is the image of the object SQ.

In Fig. 15.16, size of image $= II_1 = 2$ cm.

Actual size of the image $= 2\times 0.05$ m $=$ 0.1 m.

In Fig. 15.16, distance of the image from concave mirror $= OI = 12$ cm.

Actual distance of the image from concave mirror $= 12\times 0.05$ m $= 0.6$ m.

Since the image is in front of the mirror, it is real.

Analytic method

$u = -0.3$ m ($-$sign as the object is to the left of mirror)

$f = -\frac{R}{2} = -0.2$ m (f of concave mirror is negative)

From mirror formula

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}\text{, or}$$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = -\frac{1}{0.2\text{ m}} + \frac{1}{0.3\text{ m}}$$

$$= \frac{-0.1}{0.3\times 0.2\text{ m}}$$

$v = -0.6$ m ($-$sign means image is to the left of mirror, i.e. it is a real image)

$$\text{Magnification} = \frac{v}{u} = \frac{-0.6\text{ m}}{-0.3\text{ m}} = 2.$$

Height of the image $=$ magnification $\times$ height of the object $= 2\times 0.05$ m $= 0.1$ m.

Answer An inverted image of size 0.1 m is formed at a distance of 0.6 m in front of the concave mirror.

Suggestion We advise that you should draw the ray diagram on a graph paper. Because of squares on the graph paper you will not commit any error in drawing the parallel lines and in measurements.

EXAMPLE 15.4 A needle 0.03 m long is placed in front of a concave mirror of focal length 0.12 m, such that its length is perpendicular to the principal axis. Determine the position and height of the image of the needle. Distance of the needle from the mirror is 0.06 m.

Graphical solution Let the scale of Fig. 15.17 be 1 cm $= 0.03$ m. Following Example 15.3 we draw Fig. 15.17.

(a) A ray QQ_2 (it would pass through the focus if produced backwards) after reflection from the mirror becomes parallel to the principal axis PA. Thus Q_2S_2 is the reflected ray.

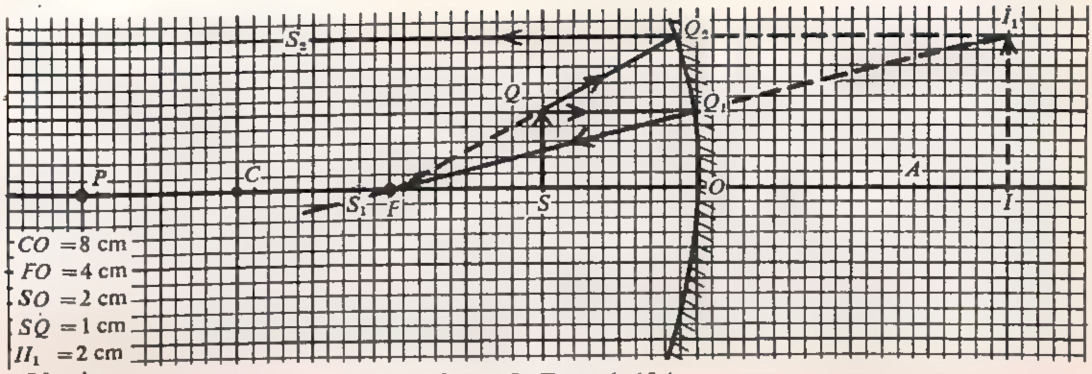


FIG. 15.17 Example 15.4.

(b) A ray QQ_1 parallel to the principal axis after reflection passes through the focus F. The reflected ray is Q_1FS_1.

These two reflected rays do not meet anywhere on the left of the mirror. However, on producing backward they meet at I_1. The perpendicular II_1 to the principal axis is the image.

In the figure, $II_1 = 2$ cm.

Actual size of the virtual image $= 2 \times 0.03$ cm $= 0.06$ m.

In the figure, $OI = 4$ cm.

Actual distance of the image from the concave mirror $= 4 \times 0.03$ m $= 0.12$ m.

Since the rays do not pass through the image it is virtual (image is behind the mirror).

Analytic method $u = -0.06$ m and $f = -0.12$ m. From the mirror formula,

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$

$$= \frac{1}{-0.12\text{ m}} + \frac{1}{0.06\text{ m}} = \frac{0.06}{0.12 \times 0.06\text{m}}$$

or, $v = 0.12\ m$ (+sign indicates that the image is behind the mirror)

$$\text{Magnification} = \frac{v}{u} = \frac{0.12\text{ m}}{0.06\text{ m}} = 2$$

Height of the image = magnification × height of the needle

$$= 2 \times 0.03\text{ m} = 0.06\text{ m}.$$

Answer The size of the virtual image is 0.06 m. It is formed behind the mirror at a distance of 0.12 m from the pole.

EXAMPLE 15.5 An object of length 0.2 m is placed in front of a convex mirror of focal length 0.3 m at a distance of 0.6 m. Determine the position of the image and its magnification.

Graphical solution Let the scale of Fig. 15.18 be 1 cm = 0.1 m. Fig. 15.18 is obtained follow-

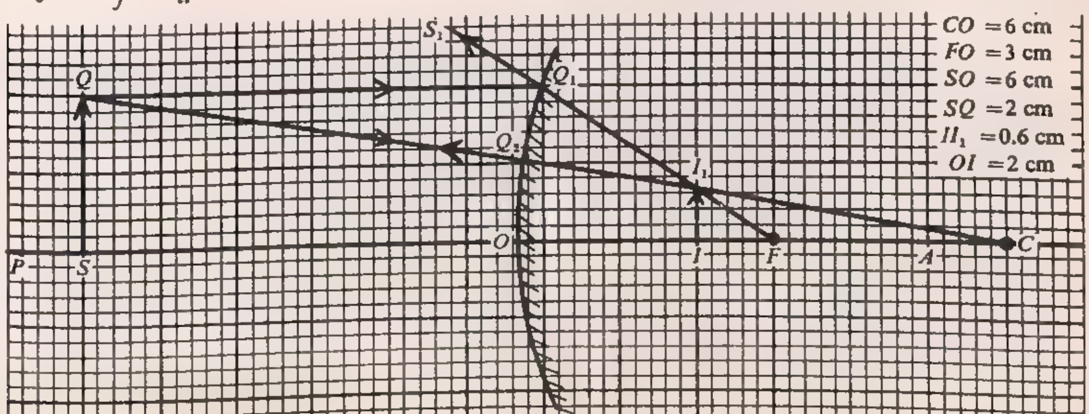


FIG. 15.18 Example 15.5.

ing Example 15.3. In this case the two reflected rays are obtained as follows.

(a) QQ_2 which remains unbent as it passes through the centre of curvature.

(b) QQ_1 which is parallel to the principal axis. This ray after reflection would pass through the focus. Hence Q_1S_1 is the reflected ray.

These two reflected rays do not meet on the left of the mirror. However, they meet behind the mirror at I_1. I_1I, perpendicular to the principal axis, is the image of the object SQ. Since the image is formed behind the mirror, i.e. the rays do not actually pass through it, it is virtual. In Fig. 15.18, $II_1 = 0.6$ cm. Hence the actual height of the image $= 0.6 \times 0.1$ m $= 0.06$ m.

$$\text{Magnification} = \frac{\text{height of image}}{\text{height of object}}$$

$$= \frac{0.06 \text{ m}}{0.2 \text{ m}} = 0.3$$

In Fig. 15.18 $OI = 2$ cm. Hence the distance of the image from the mirror $= 2 \times 0.1$ m $= 0.2$ m.

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{0.3 \text{ m}} + \frac{1}{0.6 \text{ m}}$$

or, $\quad v = 0.2$ m.

$$\text{Magnification} = \frac{v}{u} = \frac{0.2 \text{ m}}{-0.6 \text{ m}} = -0.33.$$

Answer The image is virtual, formed at a distance of 0.2 m behind the convex mirror. Magnification is 0.33.

Suggestion Attempt graphical solutions of Examples 15.3, 15.4 and 15.5 with two other rays.

NOTE The difference in the value of the magnification by the two methods is because we cannot measure distances less than 0.1 cm by an ordinary scale.

EXAMPLE 15.6 An object of length 0.04 m is placed between the focus and the radius of curvature, in front of a concave mirror. Determine the magnification if the image length is 0.06 m.

Solution Since the mirror is concave and the object is placed between the focus and the radius of curvature, the image is real.

$$m = \text{magnification} = \frac{\text{image length}}{\text{object length}}$$

$$= \frac{0.06 \text{ m}}{0.04 \text{ m}} = 1.5 \text{ (positive sign as the image is real)}$$

Answer The magnification is 1.5.

EXAMPLE 15.7 Determine the magnification when an image of an object 0.2 m away from the mirror is formed 0.4 m behind the mirror.

Solution $u = -0.2$ m and $v = 0.4$ m

$$m = \frac{v}{u} = \frac{0.4 \text{ m}}{-0.2 \text{ m}} = -2 \text{ (negative sign indicates that the image is virtual)}$$

Answer The magnification is -2.

EXAMPLE 15.8 A concave mirror is placed 1 m away from a screen. Where should a bulb be placed so that its 2.5 times magnified image is obtained on the screen?

Solution Since the image is obtained on the screen, it is real. Let the screen be placed to the left of the mirror. Then, $m = 2.5$ (as the image is real) and $v = -1$ m ($-$sign as the image is to the left of the mirror). $u = ?$

$$m = \frac{v}{u} = 2.5, \text{ or}$$

$$u = \frac{v}{2.5} = \frac{-1}{2.5} = -0.4 \text{ m}.$$

Answer The bulb should be placed 0.4 m to the left of the mirror.

EXAMPLE 15.9 Where should one place an object in front of a concave mirror in order to obtain an image of the same size. What will be the image distance?

Solution According to the question, image size = object size.

$$m = \frac{\text{image size}}{\text{object size}} = \frac{v}{u} = 1$$

or, $\quad v = u.$

from the mirror formula,

$$\frac{1}{f} = \frac{1}{u}+\frac{1}{v} = \frac{2}{u}, \text{ or}$$

$$u = 2f = R.$$

Since the object distance is equal to the radius of curvature, the object is at the centre of curvature. Further as $v = u$, the image distance is equal to the radius of curvature.

Answer The object should be placed at the centre of curvature. The image distance is equal to the radius of curvature.

EXAMPLE 15.10 When an object is placed 0.3 m in front of a convex mirror, the image obtained is half the size of the object. Determine the focal length of the convex mirror.

Solution $u = -0.3$ m and $m = -0.5$ (the image is virtual).

$$m = \frac{v}{u}, \text{ or } v = mu = -0.3 \text{ m} \times (-0.5)$$

$$= 0.15 \text{ m}.$$

From mirror formula,

$$\frac{1}{f} = \frac{1}{v}+\frac{1}{u} = \frac{1}{0.15 \text{ m}}-\frac{1}{0.3 \text{ m}}$$

or, $f = 0.3$ m.

Answer The focal length of the convex mirror is 0.3 m.

EXAMPLE 15.11 At what distance should a candle be placed in front of a concave mirror of focal length 0.16 m such that the image is (i) real (ii) virtual, and is four times the size of the object?

Solution $f = -0.16$ m (− sign as the mirror is concave). *For real image* u and v are of the same sign (negative), and $m = 4$.

$$m = \frac{v}{u}, \text{ or } v = 4u.$$

From mirror formula

$$\frac{1}{f} = \frac{1}{v}+\frac{1}{u} = \frac{1}{4u}+\frac{1}{u} = \frac{5}{4u}$$

or, $4u = 5f$

$$u = \frac{5f}{4} = \frac{-5\times 0.16 \text{ m}}{4} = -0.20 \text{ m}.$$

For virtual image u is negative and v is positive, or, $v = -4u$.

$$\frac{1}{f} = \frac{1}{v}+\frac{1}{u} = \frac{-1}{4u}+\frac{1}{u} = \frac{3}{4u}$$

or, $4u = 3f$

or, $$u = \frac{3f}{4} = \frac{-3\times 0.16 \text{ m}}{4} = -0.12 \text{ m}.$$

Answer For real image the object should be placed 0.20 m in front of the concave mirror. For virtual image the object should be placed 0.12 m in front of the concave mirror.

EXAMPLE 15.12 A concave mirror produces an inverted image three times the size of the object. If the distance between image and object is 0.4 m, determine the focal length of the concave mirror, position of the object and that of the image.

Solution Since the image is inverted, it is real. The object and the image both are on the same side of the concave mirror. $m = 3$. $m = v/u$ or $v = 3u$, i.e. image will be more to the left of the concave mirror than the object. Let the distance of the object from the concave mirror $= a$. $u = -a$.

$$v = -(a+0.4 \text{ m}).$$

But $v = 3u$, or

$$-3a = -a-0.4 \text{ m}, \text{ or } a = 0.2 \text{ m}$$

Hence $u = -0.2$ m, and $v = -0.6$ m.

From mirror formula,

$$\frac{1}{f} = \frac{1}{v}+\frac{1}{u} = -\frac{1}{0.2 \text{ m}}-\frac{1}{0.6 \text{ m}}$$

$$= -\frac{4}{0.6 \text{ m}}$$

$$f = -0.6 \text{ m}/4 = -0.15 \text{ m}.$$

Answer The focal length of the concave mirror is 0.15 m. The object and the image are 0.2 m and 0.6 m respectively in front of the concave mirror.

EXAMPLE 15.13 Suppose a person not knowing physics approaches you to seek help. His problem is what kind of mirror he should purchase so that while shaving he should be able to see an erect image of his face of about twice the size. He wishes to keep his face 0.6 m away from the mirror. What will be your advice about the nature of the mirror and its radius of curvature?

Solution If you have read this chapter carefully you must have noticed that a convex mirror can never produce an image larger than the size of the object. However, a concave mirror does produce an image larger than the object. Therefore, the spherical mirror must be concave. Here $u = -0.6$ m, and $m = 2$.

$$v = mu = 2\,u = -1.2 \text{ m}.$$

From the lens formula,

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} = -\frac{1}{0.6 \text{ m}} - \frac{1}{1.2 \text{ m}}$$

$$= -\frac{3}{1.2 \text{ m}}$$

or,
$$f = -0.4 \text{ m}.$$
$$R = 2f = -0.8 \text{ m}$$

Answer You must tell the gentleman to buy a concave mirror of radius of curvature = 0.8 m.

EXAMPLE 15.14 A boy on a full moon night obtained an image of the moon on a screen at a distance of 185 cm in front of a concave mirror. The diameter of the image comes out to be 1.75 cm. He knew that the diameter of the moon is about 3500 km. Help him in finding out the distance of the moon from the surface of the earth.

Solution Diameter of the image = 1.75 cm = 0.0175 m, diameter of the moon = 3500 km = 3.5×10^6 m, and $v = -185$ cm = -1.85 m.

$$m = \frac{0.0175 \text{ m}}{3.5 \times 10^6 \text{ m}} = 5 \times 10^{-9} = \frac{v}{u}$$

or,
$$u = \frac{v}{5 \times 10^{-9}} = \frac{1.85 \text{ m}}{5 \times 10^{-9}} = 3.7 \times 10^8 \text{ m}$$

$$= 3.7 \times 10^8 \text{ km}.$$

Answer The distance of the moon from the surface of the earth is 3.7×10^8 km.

PROBLEMS

15.1 A convex mirror is constructed from a glass sphere of radius 0.3 m. What is the radius of curvature and the focal length of the convex mirror?

15.2 When a small light bulb is placed 0.2 m in front of a concave mirror the reflected rays become parallel. Find out the focal length and the radius of curvature of the mirror.

15.3 One of the requirements of a search light or a car headlight is that the light rays coming out of it should be parallel. Where should one place a bulb in front of a concave mirror of a search light, if the radius of curvature of the concave mirror is 0.7 m?

15.4 What kind of spherical mirror will produce an image of the sun, 50 cm from the mirror?

15.5 The image of an object placed 40 cm in front of a concave mirror is formed at the position of the object. Determine the focal length of the concave mirror.

15.6 A pencil is placed in front of a concave mirror of focal length 10 cm. The position of the pencil is adjusted till an inverted image is obtained over the pencil itself. How far is the pencil from the mirror?

15.7 The inverted image of a lamp placed 40 cm in front of a concave mirror is obtained on a screen at a distance of 1.2 m from the concave

mirror. Find the focal length of the concave mirror. Is the image real?

15.8 Dentists and ENT (ear-nose-throat) specialists make use of a concave mirror in examining the diseased part. Suppose an ENT surgeon has a concave mirror of radius of curvature 0.7 m. He places a lamp 0.6 m away from the mirror. How far should the inner part of the throat be from the mirror so that the doctor can see it clearly? (*Hint*: For best examination, the image of the lamp should be formed at the part to be examined, so that it is well lighted).

15.9 An object is magnified two times by a mirror. Determine the magnification if the image is (i) real, (ii) virtual.

15.10 What will be the magnification if an image is formed by (i) concave mirror, (ii) convex mirror, if the object is 1.6 cm high and the image is 0.4 cm high? Is the image real?

15.11 An object placed between focus and optical centre of a mirror produces an image twice the size of the object. Determine the magnification.

15.12 How far will a (i) real, (ii) virtual image of height 5 cm be formed if the object is of height 2.5 cm and is placed 40 cm in front of a mirror?

15.13 Find out the position of the image of an object 0.6 m away from the mirror when the magnification is (i) 2, (ii) $-1/2$.

15.14 A candle of height 0.03 m is placed 0.15 m to the left of a concave mirror. Find the nature and size of the image formed if it is (i) 0.2 m to the left of the mirror, (ii) 0.2 m to the right of the mirror.

15.15 How high is the object if its image, 0.02 m high, is formed 0.6 m in front of the mirror? The object is 0.3 m in front of the mirror.

15.16 A pencil 2 cm high is placed in front of a mirror at a distance of 0.6 m. It is desired to obtain an image 4 cm high on a screen placed in front of the mirror. What kind of spherical mirror should be used, and where should the screen be placed?

15.17 Suppose we want to measure the height and the distance of a given building from a point. For this purpose we take a concave mirror of focal length 50 cm. An image of the building 2 cm high is obtained on a screen 50.5 cm away from the concave mirror. Determine the height and distance of the building from the mirror.

15.18 A concave mirror produces an image half the size of the object at a distance of 90 cm from the mirror. Determine the position of the object and the focal length of the mirror.

15.19 Where should one place an object in front of a (i) concave, (ii) convex mirror of radius of curvature 80 cm such that the image is one quarter the size of the object? Also find the position of the image.

15.20 Where should a man stand in front of a concave mirror of radius of curvature 1.6 m such that his (i) real, (ii) virtual image is twice his size?

15.21 A candle is placed 0.3 m from a screen. Where should one place a concave mirror to obtain an image thrice the size of the candle on the screen? Also calculate the focal length of the concave mirror.

15.22 An object 1 cm high perpendicular to the principal axis is placed 30 cm away from a mirror of radius of curvature 40 cm. Determine graphically the position, nature and magnification of the image for (i) concave mirror, (ii) convex mirror.

15.23 An object 10 cm high is placed in front of a concave mirror of focal length 50 cm. The object is perpendicular to the principal axis and is at a distance of 1.5 m from the mirror. Draw a neat diagram and find out the position and height of the image.

15.24 The image of an object perpendicular to the principal axis is formed 40 cm in front of a concave mirror of focal length 24 cm. If the height of the image is 4 cm, calculate the position and height of the object.

15.25 An object is placed 20 cm away from a concave mirror of focal length 10 cm. Find the position and nature of the image.

16 Refraction and Lenses

Refraction is another interesting phenomenon of light. It is observed when light passes from one medium to another medium. One of the most important applications of this phenomenon is in making lenses which have been in use since ancient times. Lenses are one of the most widely used objects in day to day life, and by scientists. The apparent bending of a rod in water and the mirage are two of the commonly observed phenomena based on refraction.

16.1 REFRACTION

Besides reflection, refraction of light is an important phenomenon which finds various applications. Refraction occurs because light travels in the form of waves which have different velocities in different optical mediums.

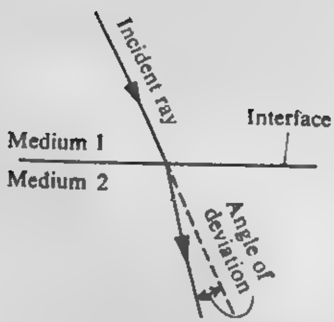


FIG. 16.1 **Refraction is the phenomenon in which light changes its direction while going from one optical medium to another.**

D.16.1 Interface of Two Mediums A surface or boundary which separates one medium from another. See Fig. 16.1.

PICTORIAL REPRESENTATION A thick line, with appropriate shading and/or labelling for the two mediums.

D.16.2 Deviation The phenomenon of the change of direction of a ray of light when it passes from one medium to another.

WRITTEN REPRESENTATION No specific symbol.

SPECIFICATION The angle (Fig. 16.1) which the refracted ray (D.16.4) makes with the direction of the incident ray. Measured in degrees (°), minutes (′) and seconds (″).

D.16.3 Refraction of Light (*or, simply, Refraction*) The phenomenon of the change of direction of a ray of light when it passes from one medium to another.

NOTE Reflection occurs when light is incident on the surface of a body or medium which turns the light back from that surface itself. Refraction occurs when light is incident on the

surface of a body or medium which allows the light to pass through that medium.

D.16.4 Refracted Ray The ray of light in the second medium after deviation has occurred at the interface. See Fig. 16.1.

D.16.5 Angle of Refraction Measure of the deviation of the refracted ray. See Fig. 16.2.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION θ_r

SPECIFICATION The angle made by the refracted ray with the normal at the point where the ray enters the second medium. Measured in degrees (°), minutes (′) and seconds (″).

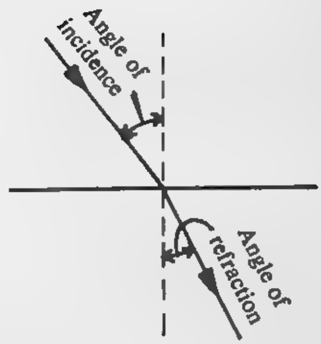


FIG. 16.2 The angle of refraction is the angle between the normal and the refracted ray.

16.2 THE LAWS OF REFRACTION

Just as a ray of light when reflected obeys certain laws, the light in a refraction phenomenon also obeys certain laws.

LAW 18: THE FIRST LAW OF REFRACTION

The incident ray, the refracted ray, and the normal to the interface at the point of incidence, all lie in the same plane.

LAW 19: THE SECOND LAW OF REFRACTION (Snell's Law)

For a particular pair of mediums and for a particular wavelength of light, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant.

MATHEMATICAL EXPRESSION

$$\frac{\sin \theta_i}{\sin \theta_r} = \text{constant} \qquad (E.16.1)$$

D.16.6 Absolute Refractive Index (*or, simply, Refractive Index*) The characteristic of the refractive property of a material given by the constant in Snell's Law, E.16.1, when the first medium is vacuum and the second medium is the given material.

TYPE OF QUANTITY Here taken as a scalar.

WRITTEN REPRESENTATION n or μ.

SPECIFICATION From E.16.1

$$n = \frac{\sin \theta_i}{\sin \theta_r} \qquad (E.16.2)$$

when light of a particular wavelength travels from vacuum into a material medium.

NOTES (i) No two materials have the same absolute refractive index.

(ii) For all material mediums

$$n > 1 \qquad (E.16.3)$$

D.16.7 Relative Refractive Index The value of the constant in Snell's law when both the mediums in the refraction phenomenon are material mediums.

TYPE OF QUANTITY Here treated as a scalar.

WRITTEN REPRESENTATION μ_{12} or μ_{ab} where 1 (or a) and 2 (or b) are labels for the first and the second material mediums respectively; the order of the subscripts depends on the direction of light (e.g. μ_{21} represents the relative refractive index of medium 1 with respect to medium 2, when light first traverses medium 2 and then medium 1).

SPECIFICATION From Snell's law

$$\mu_{12} = \frac{\sin \theta_i}{\sin \theta_r} \qquad (E.16.4)$$

NOTES (i) The relative refractive index is the property of medium 2 with respect to medium 1. When medium 1 is vacuum $\mu_{12} = n_2$.

(ii) For a given pair of mediums

$$\mu_{12} > 1 \text{ or } \mu_{12} < 1 \text{ but } \mu_{12} \neq 1 \qquad (E.16.5)$$

(iii)

$$\mu_{12} = \frac{n_2}{n_1} \qquad (E.16.6)$$

(iv) When light travels from one medium to another, the extent of bending in the ray of light will depend on the magnitude of the relative refractive index of medium 2 with respect to medium 1. Greater the relative refractive index, more is the extent of bending or deviation.

THE SPEED OF LIGHT AND REFRACTIVE INDEX Light travels at a constant speed of 3.000×10^8 ms^{-1} in *vacuum* under all conditions. But in all material mediums light always travels at slower speeds. The speed of light is a characteristic for a material medium for *all* wavelengths of light. The absolute and relative refractive indices of a material medium can be defined in terms of the speed of light as follows

$$n = \frac{\text{speed of light in vacuum}}{\text{speed of light in material medium}} \qquad (E.16.7)$$

and

$$\mu_{12} = \frac{\text{speed of light in medium 1}}{\text{speed of light in medium 2}} \qquad (E.16.8)$$

E.16.7 and E.16.8 give E.16.6. Also E.16.5 can be easily understood using E.16.7 and E.16.8. As the speed of light is different in each material medium, μ_{12} will be greater or less than 1, depending or whether the speed of light is greater or lesser in the first medium than in the second medium. E.16.8 also tells us that

$$\mu_{12} = \frac{1}{\mu_{21}} \qquad (E.16.9)$$

D.16.8 Optically Denser and Rarer Mediums

(i) A medium 2 is optically denser than a medium 1 if

$$\mu_{12} > 1 \text{ or } n_2 > n_1 \qquad (E.16.10)$$

EXAMPLES Carbon disulphide ($n = 1.63$) is optically denser than ethyl alcohol ($n = 1.36$) or water ($n = 1.33$).

(ii) A medium 2 is optically rarer than a medium 1 if

$$\mu_{12} < 1 \text{ or } n_2 < n_1 \qquad (E.16.11)$$

EXAMPLES Water ($n = 1.33$) is optically rarer than glass ($n = 1.5$).

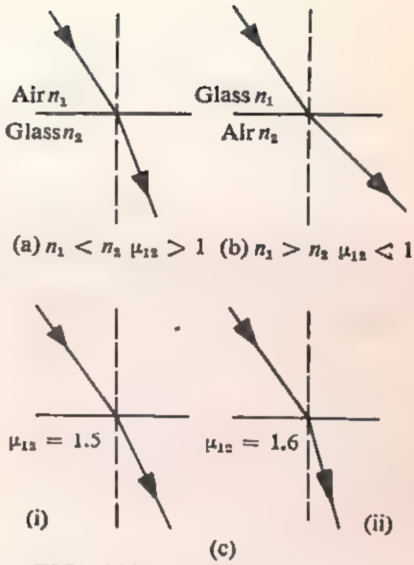


FIG. 16.3 (a) $n_1 < n_2$, $\mu_{12} > 1$. When light travels from an optically rarer to an optically denser medium, the refracted ray bends towards the normal. (b) $n_1 > n_2$, $\mu_{12} < 1$. When light travels from an optically denser to an optically rarer medium, the refracted ray bends away from the normal. (c) The extent of bending depends on the relative refractive index of the medium.

D.16.9 Prism A refracting optical medium with intersecting plane regular surfaces. See Fig. 16.4.

PICTORIAL REPRESENTATION A triangle.

FIG. 16.4 A prism.

16.3 LENSES

Refraction obeys the same laws, whether light is incident on a plane interface or a curved interface. But at a curved interface the behaviour of light is very different due to the curvature of the interface.

D.16.10 Lens A piece of transparent material, like glass or plastic or a natural crystal, having at least one curved surface.

PICTORIAL REPRESENTATION By an area bounded by two lines, at least one of them being curved.

EXAMPLES Lenses in spectacles, telescopes, microscopes, etc.

D.16.11 Spherical Lens A lens with at least one curved surface which is a part of a sphere.

PICTORIAL REPRESENTATION By an area bounded by two arcs (parts of circles), or a straight line and an arc of a circle. See Fig. 16.5.

EXAMPLES Lens used by watch repairers, in cameras, slide projectors, etc.

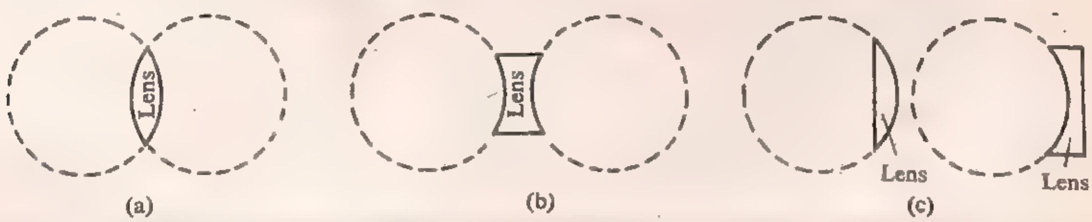


FIG. 16.5 Spherical lens. Either both the refracting surfaces or one of them is a part of a hollow sphere.

NOTE There are two basic forms of spherical lenses. See D.16.13 and D.16.14.

D.16.12 Cylindrical Lens A lens with at least one curved surface which is cylindrical.

EXAMPLES In spectacles to correct a kind of eye defect, see D.17.13. In cameras, as a part of the compound lens system.

D.16.13 Converging Lens A lens which is capable of bringing together or concentrating (or converging) incident light rays in one area or at one point.

EXAMPLES Lens used to focus sunlight.

NOTE Sometimes a converging lens is also known as a *positive* lens as its primary focal length (D.16.21) is *positive.*

D.16.14 Diverging Lens A lens which cannot concentrate light rays to a point or area, but causes them to diverge. The light rays then appear to come from a point or area.

EXAMPLES Used in spectacles to correct a kind of eye defect (myopia), see D.17.11.

NOTE Sometimes a diverging lens is also known as a *negative* lens because its primary focal length (D.16.21) is *negative.*

EQUIVALENCE BETWEEN LENSES AND PRISM SYSTEMS From Fig. 16.6 it is clear that converging lenses and diverging lenses act in a way similar to an arrangement of prisms. This 'equivalence'

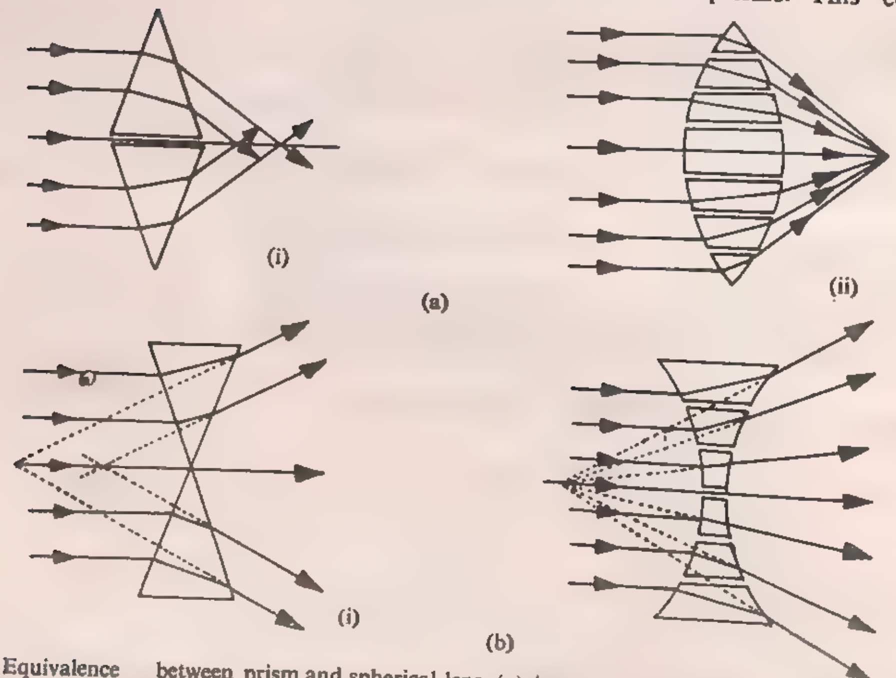


FIG. 16.6 Equivalence between prism and spherical lens. (a) A convex lens is equivalent in action to a combination of two prisms placed together base to base. The parallel incident beam becomes convergent. (b) A concave lens is equivalent in action to a combination of two prisms placed together vertex to vertex. The parallel beam becomes divergent.

shows us that the refraction of light by a curved surface (lens) takes place in almost the same way as the refraction by a plane surface (prism).

D.16.15 Concave Spherical Lens A spherical lens which is thinner at the centre than at the edge.

EXAMPLES See Fig. 16.7.

NOTES (i) These lenses are diverging in nature.

(ii) By convention the word *concave lens* is used for a *biconcave lens* (i.e. a lens which is concave on both sides).

D.16.16 Convex Spherical Lens A spherical lens which is thicker at the centre than at the edges.

EXAMPLES See Fig. 16.8.

NOTES (i) These lenses are converging in nature.

(ii) By convention the word *convex lens* is used for a *biconvex lens* (i.e. a lens which is convex on both sides).

16.4 CHARACTERISTICS OF SPHERICAL LENSES

Spherical lenses are the easiest to understand and will be dealt with here. They are also the most commonly and widely used type of lenses. The concepts used in the study of lenses are similar to the ones used for understanding spherical mirrors.

D.16.17 Centre of Curvature The centres of the spheres on which the surfaces of the lens lie. See Fig. 16.9.

PICTORIAL REPRESENTATION Two points marked on a diagram, which are the centres of the two spherical surfaces of the lens. Labelled as C_1 and C_2.

NOTES (i) Each spherical lens has two centres of curvature, usually located on opposite sides.

(ii) The centre of curvature of a plane surface of a lens is at infinity. Hence the lens which has one plane surface has only one centre of curvature marked in the diagram.

D.16.18 Principal Axis The straight line passing through both the centres of curvature of a lens. See Fig. 16.10.

PICTORIAL REPRESENTATION The line joining C_1 and C_2 and extended beyond.

NOTE If one of the surfaces is plane, the principal axis is the line through the centre of curvature of the curved surface and perpendicular to the plane surface.

D.16.19 Optical Centre The point on the principal axis and inside a lens, such that light passing through it, at any angle of

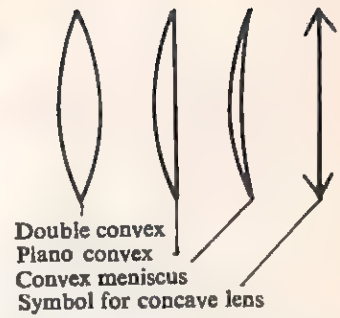


FIG. 16.7 Three types of convex lenses. Note that the lens has *maximum* thickness at the centre.

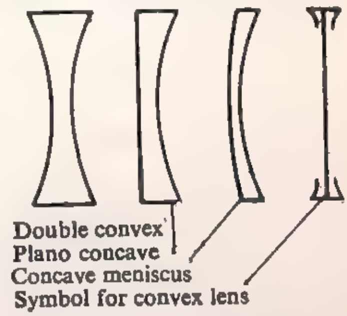


FIG. 16.8 Three types of concave lenses. Note that the lens has *minimum* thickness at the centre.

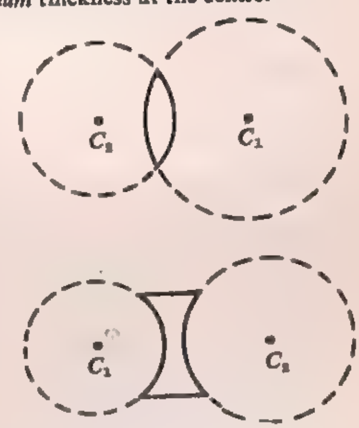


FIG. 16.9 Centre of curvature. C_1 and C_2 are the centres of the hollow spheres to which the left and right surfaces of the lens respectively belong.

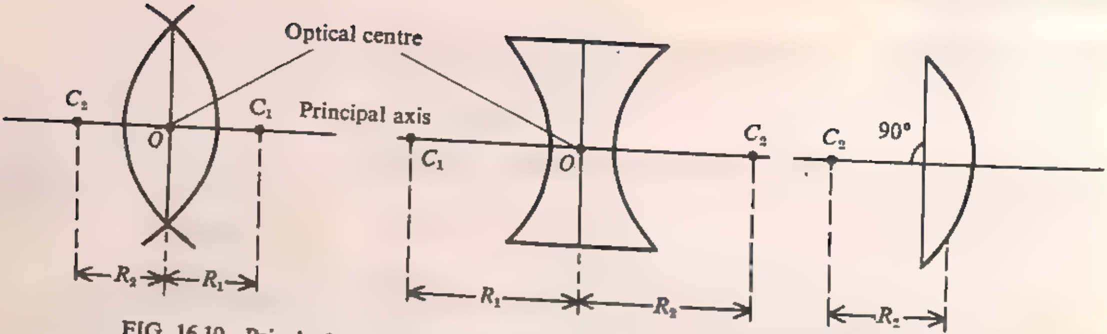


FIG. 16.10 Principal axis, optical centre, centre of the lens, and radii of curvature.

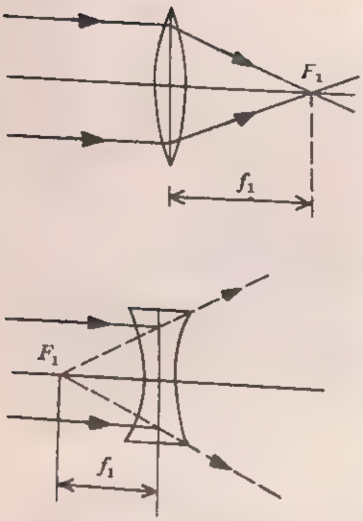


FIG. 16.11 Primary focus is a point to which a parallel incident beam from the left converges or appears to diverge from. For a convex lens it is a real point while for a concave lens it is a virtual point. It is the image of an object at infinity.

incidence on the surface of the lens, is not deviated.

PICTORIAL REPRESENTATION Labelled as O.

D.16.20 Focal Point (*or, simply, Focus*) The point to which all the rays which are parallel to the principal axis during incidence, converge or appear to come from, after refraction by the lens. See Fig. 16.11 and Fig. 16.12.

NOTES (i) Every lens, except those having one plane surface, because of the two refracting surfaces, has two focuses, which are usually situated on opposite sides of the lens. See D.16.21 and D.16.22.

(ii) In a converging lens, the focus is a real point whereas in a diverging lens, the focus is a virtual point.

D.16.21 Primary (*or* **Principal** *or* **First**) **Focus** (*or, simply, Focus*) The point to which all the parallel incident rays travelling from left to right physically converge or appear to diverge from,after refraction by the lens. See Fig. 16.11.

PICTORIAL REPRESENTATION By a point marked on the principal axis. Labelled as F_1.

D.16.22 Secondary (*or,* **Second**) **Focus** The object point, real or virtual, the image of which is formed at infinity, to the right of the lens. In this case the refracted parallel beam travels from left to right, on the right of the lens. See Fig. 16.12.

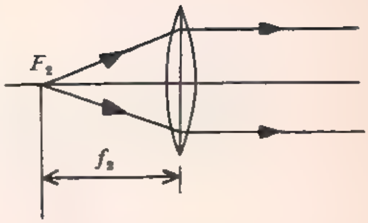
PICTORIAL REPRESENTATION By a point marked on the principal axis. Labelled as F_2.

D.16.23 Focal Length A measure of the power of convergence or divergence of a given lens.

TYPE OF QUANTITY Scalar, with a sign.

WRITTEN REPRESENTATION f_1, f_2

SPECIFICATION The distance from a focal point to the optical centre of a lens. Measured in metre (m).



D.16.24 Primary (*or* **Principal** *or* **First) Focal Length** (*or, simply, Focal Length*) The distance from the primary focal point to the optical centre of a lens. See Fig. 16.11.

TYPE OF QUANTITY Scalar, positive for a converging lens and negative for a diverging lens.

WRITTEN REPRESENTATION f_1

SPECIFICATION Magnitude measured in metre (m).

NOTE Whenever a lens is supplied by the manufacturer, the focal length written on it is the primary focal length.

D.16.25 Secondary (*or* **Second) Focal Length** The distance from the secondary focal point to the optical centre of a lens. See Fig. 16.12.

TYPE OF QUANTITY Scalar, negative for a converging lens and positive for a diverging lens.

WRITTEN REPRESENTATION f_2

SPECIFICATION Magnitude measured in metre (m).

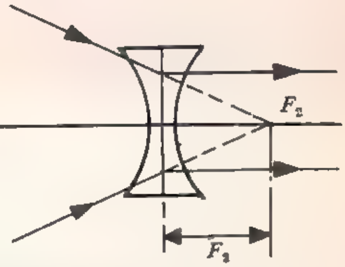


FIG. 16.12 The secondary focus is a point where, if an object (real or virtual) is placed, the refracted beam to the right of the lens will be a parallel beam. For a convex lens it is a real point and for a concave lens it is a virtual point. It is the object position when the image is formed at infinity on the right of the lens.

D.16.26 Thin Lens A lens with thickness much less than either of its focal lengths.

NOTE As you will learn we have to normally deal with thin lenses during our study. In practice, we may often have to deal with thick lenses. In the latter case, our present study is not really adequate.

D.16.27 Principal Section A plane perpendicular to the principal axis and passing through the optical centre. See Fig. 16.13.

NOTE For all practical purposes a thin lens can be replaced by a principal section. We can assume that the light falls on this section and is deviated from it.

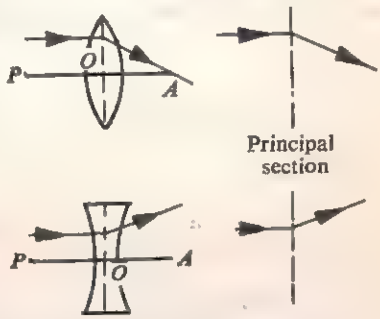


FIG. 16.13 Principal section. For the purpose of geometrical construction a lens is replaced by its principal section. The incident light is assumed to travel upto and deviate from it.

D.16.28 Dioptric Power (*or, simply, Power of a lens*) A measure of the capacity of the lens to bend a ray of light.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION No specific symbol.

SPECIFICATION The reciprocal of the primary focal length of a lens. Measured in dioptre (D) when focal length is expressed in metres.

MATHEMATICAL EXPRESSION According to the definition

$$\text{Power} = \frac{1}{\text{focal length}}$$

$$= \frac{1}{f_1} \qquad (E.16.12)$$

NOTES (i) Power of a lens is *positive* for converging lens and *negative* for diverging lens.

(ii) The power of lenses used in eyeglasses normally range in magnitude from 0.25 D to 10 D.

D.16.29 Dioptre A unit to measure power of lenses.

TYPE OF QUANTITY Derived SI unit.

WRITTEN REPRESENTATION D or dioptre.

SPECIFICATION The power of a lens which has focal length equal to 1m is 1dioptre.

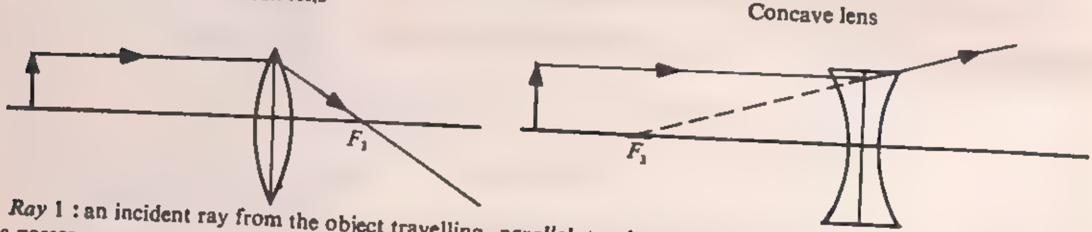
MATHEMATICAL EXPRESSION

$$1\,D = \frac{1}{1\text{ m}} = \text{m}^{-1} \qquad (E.\ 16.13)$$

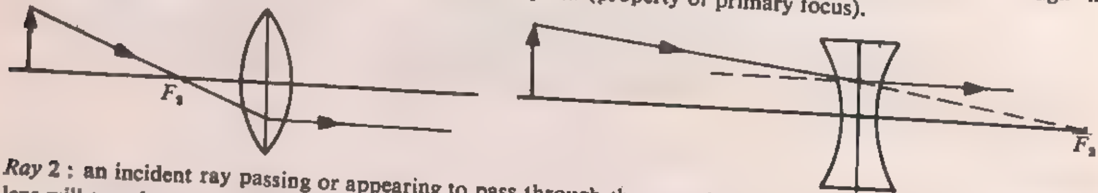
16.5 WORKING PRINCIPLES OF LENSES

(a) SIGN CONVENTION

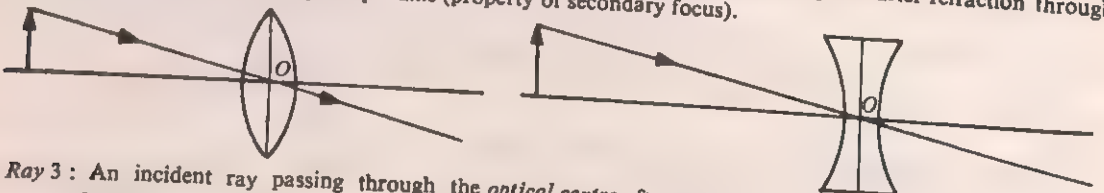
(b) IMAGE CONSTRUCTION Any two out of the three rays shown in Fig. 16.14 can be used in locating the image (similar rays were used in mirrors; see Section 15.3). A light ray is assumed to travel from left to right.



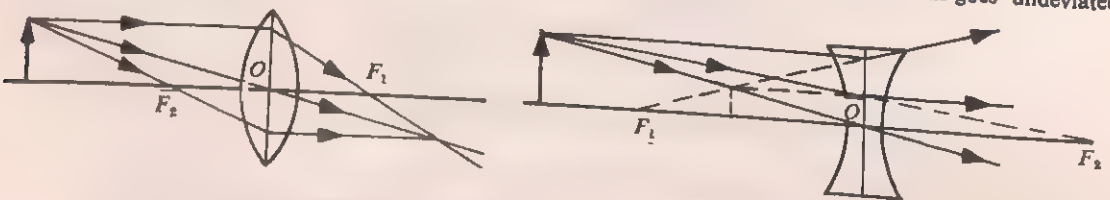
(a) *Ray* 1 : an incident ray from the object travelling *parallel* to the principal axis after refraction through the lens passes or appears to pass through the *primary focal point* (property of primary focus).



(b) *Ray* 2 : an incident ray passing or appearing to pass through the *secondary focal point* after refraction through the lens will travel *parallel* to the principal axis (property of secondary focus).



(c) *Ray* 3 : An incident ray passing through the *optical centre* after refraction through the lens goes undeviated (property of optical centre).



(d)

FIG. 16.14 The three special rays used in locating the position of the image geometrically.

(c) DISTINCTION BETWEEN GLASS SLAB, CONVEX LENS AND CONCAVE LENS Place a given piece of glass on a book, move it away from the book and note the size and nature of the image. The following three cases arise (somewhat similar to the mirrors; see Section 15.3).

1. The size of the image remains the *same* as that of the object and is *independent* of the distance between the lens and book. The piece is a *glass slab*.

2. The size of the image is always *less* than that of the object, whatever may be the distance between the lens and book. The piece of glass is a *concave lens*.

3. For certain distances between the lens and the book, the image is bigger than the object. At a certain distance it disappears. It again reappears but is bigger than the object. Its size then keeps on decreasing. The piece of glass is a *convex lens*.

(d) LENS FORMULA A relation between focal length, object distance and image distance used widely in the analytical study of instruments based on lenses.

Derivation

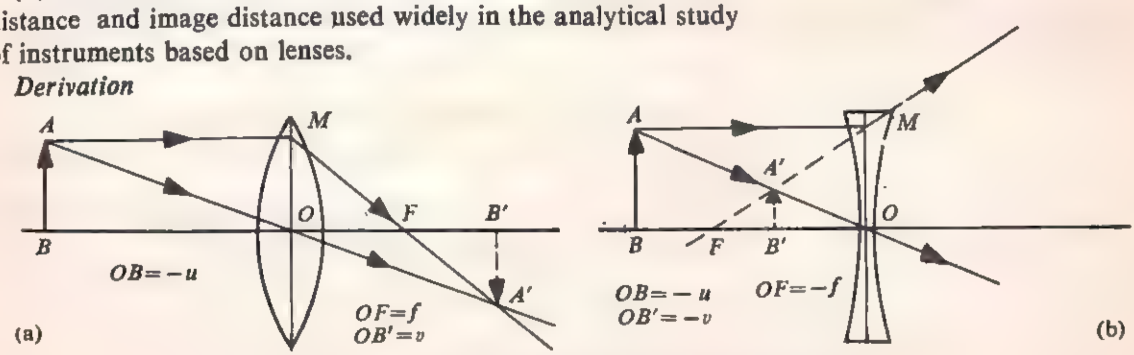


FIG. 16.15 Diagrams for the derivation of lens formula.

For convex lens (Fig. 16.15a)	*For concave lens* (Fig. 16.15b)

1. $\triangle ABO$ and $\triangle A'B'O$ are similar.

$$\frac{AB}{A'B'} = \frac{BO}{B'O} \qquad (E.\ 16.14)$$

2. $\triangle OMF$ and $\triangle A'B'F$ are similar.

$$\frac{OM}{A'B'} = \frac{OF}{B'F} \qquad (E.\ 16.15)$$

3. $$OM = AB \qquad (E.\ 16.16)$$

4. Combine E. 16.15 and E. 16.16.

$$\frac{AB}{A'B'} = \frac{OF}{B'F} \qquad (E.\ 16.17)$$

5. Combine E. 16.14 and E. 16.17

$$\frac{BO}{B'O} = \frac{OF}{B'F} \qquad (E.\ 16.18)$$

6. Substitute the values in E. 16.18.

$$\frac{-u}{v} = \frac{f}{v-f} \qquad \frac{-u}{-v} = \frac{-f}{-f+v}$$

7. Simplify

$$-uv+uf = vf \qquad uf-uv = vf$$

8. Divide by uvf and rearrange.

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \qquad (E.\ 16.19)$$

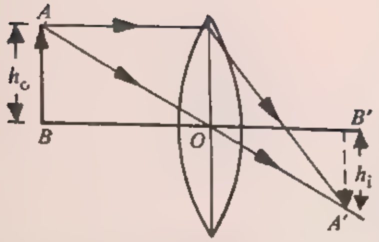


FIG. 16.16 Magnification is the ratio of image height to object height $m = h_i/h_o$

MAGNIFICATION Ratio of image height to object height. See Fig. 16.16.

From ΔAOB and $\Delta OA'B'$

$$m = \frac{A'B'}{AB} = \frac{OB}{OB'} = \frac{v}{u} \qquad (E.\ 16.20)$$

From E. 16.8

$$m = 1 - \frac{v}{f} \qquad (E.\ 16.21)$$

NOTES (i) For real images, m is *positive* and for virtual images it is *negative*. This is in contrast to mirrors (see note after D.15.19).

(ii) For concave lens, m is always negative and $|m| < 1$, while for convex lens it can be positive or negative.

SOLVED EXAMPLES

EXAMPLE 16.1 The height of an object is 5 cm and that of the image 10 cm. What is the magnification if the image is (i) real, (ii) virtual?

Solution (*i*) *For real image* Since the image is real it is inverted, that is it lies along the negative Y-axis. Hence from the sign convention :

Object height = 5 cm = 0.05 m, positive sign as the height is measured along the positive Y-axis.

Image height = −10 cm = −0.10 m. Negative sign as the height is measured along the negative Y-axis.

$$m = \frac{\text{image height}}{\text{object height}} = \frac{-0.10\text{ m}}{0.05\text{ m}} = -2.$$

(ii) *For virtual image* When the image is virtual it is upright. Hence,

Image height = 0.10 m, positive sign as the height of the image is measured along the positive Y-axis.

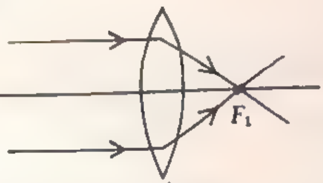
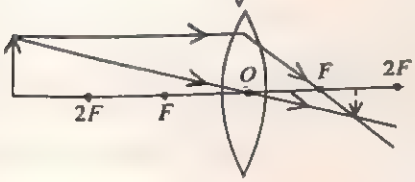
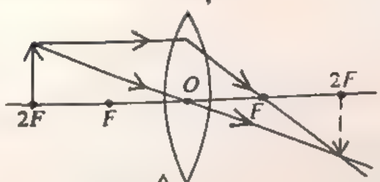
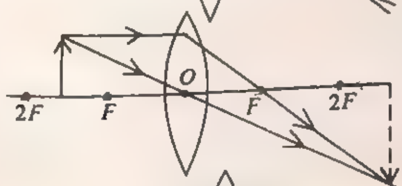
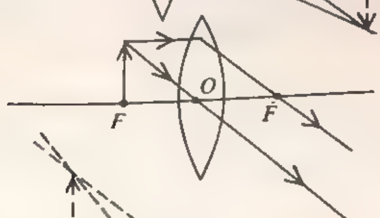
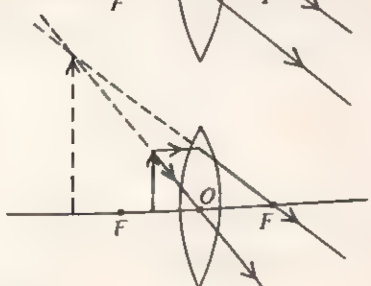
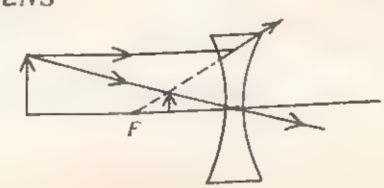
$$m = \frac{0.10\text{ m}}{0.05\text{ m}} = 2.$$

Answer The magnification is (i) for real image −2 and (ii) for virtual image 2.

EXAMPLE 16.2 Find the position of the image if the object is 0.10 m from the lens and the magnification is (i) 5, (ii) −4.

Solution Since the object is always to the left of the lens, $u = -0.10$ m, $m = v/u$ or $v = mu$.

TABLE 16.1 The object-image relationship for spherical lens for different positions of the object.

Position of object		*Position of image*	*Nature of image*	*Comparative size of the image*	*Example of application*
CONVEX LENS					
At infinity		At focus	Real and inverted	Almost a point	Telescope
Between infinity and 2F		Between F and 2F	Real and inverted	Smaller	Camera
At 2F		At 2F	Real and inverted	Same size	Camera used to copy documents
Between 2F and F		Between 2F and infinity	Real and inverted	Larger	Enlarging camera, slide projector, microscope
At F		No image, refracted rays parallel			Eyepiece of telescope, light source of parallel beam
Between F and lens		Same side as object, further away	Virtual and erect	Larger	Magnifying glass, eyepiece of telescope
CONCAVE LENS					
Anywhere		Same side as object, between lens and object	Virtual, smaller and erect	Smaller	Eye piece in Galilean telescope, lens combinations to correct eye defect (myopia)

(i) $m = 5$

$v = 5\times(-0.10\text{ m}) = -0.5\text{ m}.$

Since v is negative, the image is also to the left of the lens.

(ii) $m = -4$

$v = -4\times(-0.10\text{ m}) = 0.4\text{ m}$

Since v is positive the image is to the right of the lens.

Answer (i) Image is 0.5 m to the left of the lens. (ii) Image is 0.4 m to the right of the lens.

EXAMPLE 16.3 An object 10 cm high is placed perpendicular to the principal axis, 45 cm in front of a convex lens of focal length 20 cm. Determine the position and height of the object. Is it real or virtual?

Graphical solution Let 1 cm in Fig. 16.17 represent 10 cm.

(a) Draw a line AB which represents the principal axis.

(b) Choose a point O on AB. It represents the optical centre.

(c) The thin lens can be *replaced* by a *line* LOL_1 perpendicular to the principal axis and passing through the optical centre.

(d) At a distance of 4.5 cm from O (because the object is 45 cm from the lens) draw a line PQ 1 cm long (height of the object 10 cm) perpendicular to the principal axis. PQ represents the object.

(e) Mark two points F_1 and F_2 on the principal axis such that $OF_1 = OF_2 = 2$ cm (focal length 20 cm). F_1 is the primary focus and F_2 is the secondary focus.

(f) Since $OC_2 = 2OF_1$ and $OC_1 = 2OF_2$, two points C_1 and C_2, 4 cm from O represent the centre of curvatures.

(g) Draw a line QQ_1 parallel to the principal axis AB. This is the incident light ray parallel to the principal axis. It cuts the line LOL_1 at Q_1. This incident light ray after refraction passes through the primary focus F_1. Hence $Q_1F_1I_1$ is the refracted ray.

(h) An incident light ray QO which passes through the optical centre does not bend after refraction. Hence OI_1 is the refracted ray.

(i) Drop a perpendicular I_1I from I_1, the point of intersection of the two refracted rays, on AB. II_1 is the image of PQ.

In Fig. 16.17, $OI = 3.6$ cm.

Distance of the image from the lens $= 3.6\times 0.1\text{ m} = 0.36\text{ m}$. In Fig. 16.17, $II_1 = 0.8$ cm.

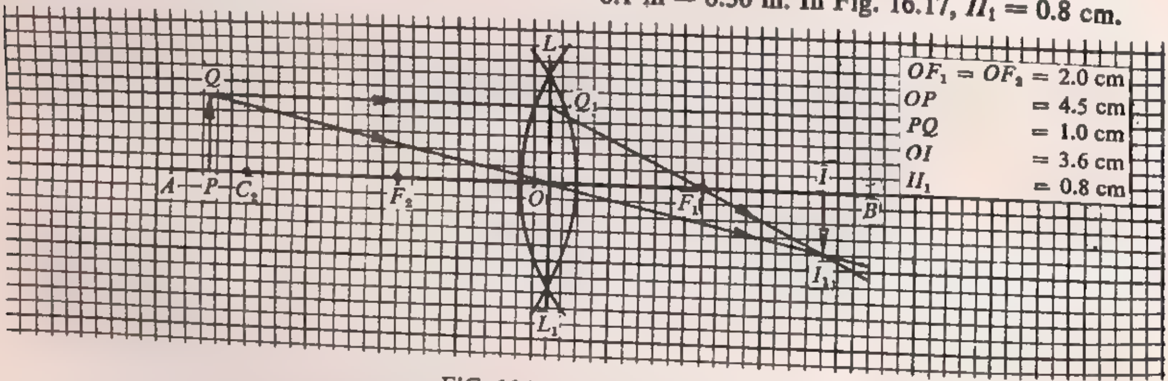


FIG. 16.17 Example 16.3.

Height of the image $= 0.8\times 0.1\text{ m} = 0.08\text{ m}$.

The image is real because the refracted rays actually pass through the image.

Analytic method $u = 45\text{ cm} = -0.45\text{ m}$ ($-$sign because object is to the left of the optical centre), and $f = 20\text{ cm} = 0.20\text{ m}$ (by convention positive for convex lens). From the lens formula,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}, \text{ or}$$

$$\frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{0.2\text{ m}} - \frac{1}{0.45\text{ m}}$$

$$= \frac{0.25}{0.2 \times 0.45 \text{ m}}$$

$v = 0.36$ m (+sign hence image is to the right of the lens)

$$m = \frac{v}{u} = \frac{0.36 \text{ m}}{-0.45 \text{ m}} = -0.8$$

($-$sign indicates image is real)

Height of the image = magnification $\times$ object height

$= -0.8 \times 0.1$ m $= -0.08$ m ($-$sign indicates that the image is real and inverted)

Answer An inverted image of height 0.08 m is formed 0.36 m to the right of the lens. The image is real.

EXAMPLE 16.4 When an object is placed 16 cm away from a convex lens, a virtual image thrice the size of the object is obtained. Determine the power of the lens and the position of the image.

Graphical solution Let the scale of Fig. 16.18 be 1 cm = 0.1 m. Follow the steps (a), (b) and (c) of the last exercise.

(b) Since the image is three times the object size it must be 3 cm high and should be to the left of the lens as it is virtual.

Draw a line A_1B_1 at a height of 3 cm. The tip of the image must touch this line.

(c) Join QO. This represents the incident light ray passing through the optical centre which will remain undeviated after refraction.

When QO is produced backwards it cuts A_1B_1 at I_1. Hence I_1 is the tip of the image. Drop a perpendicular from I_1 on AB. II_1 is the virtual image of PQ.

(d) An incident light ray parallel to the principal axis QQ_1 after refraction through the lens must pass through I_1 when produced backwards.

Join I_1 and Q_1. This line cuts the principal axis AB at F_1. F_1 is therefore the focus because an incident light ray parallel to AB after refraction must pass through the focus.

In Fig. 16.18, $OI = 4.8$ cm. Hence distance of the image from the lens $= 4.8 \times 0.1$ m $= 0.48$ m.

In Fig. 16.18, $OF_1 = 2.4$ cm. Hence the focal length $= OF_1 = 2.4 \times 0.1$ m $= 0.24$ m.

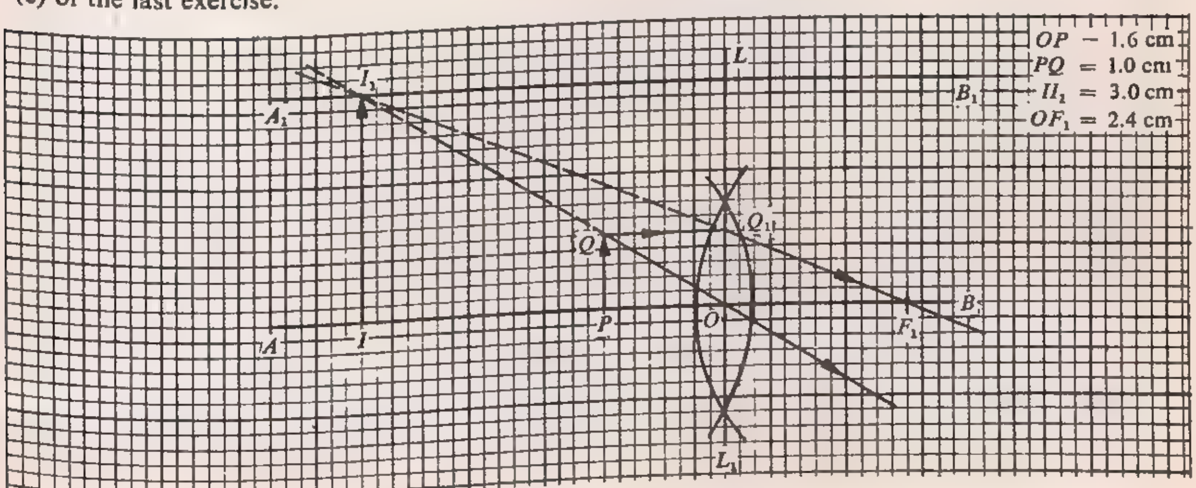


FIG. 16.18 Example 16.4.

(a) Draw a line PQ, 1 cm long (we take the object to be 1 cm high) perpendicular to AB at a distance of 1.6 cm from O (object is 0.16 m from the lens).

The image is virtual as light rays do not pass through it but appear to pass through it.

Analytic method $u = -16$ cm $= -0.16$ m, $m = 3 = v/u$, $v = 3u = -0.48$ m.

From the lens formula,

$$\frac{1}{f}=\frac{1}{v}-\frac{1}{u}=-\frac{1}{0.48\ \text{m}}+\frac{1}{0.16\ \text{m}}$$

$$f=0.24\ \text{m}.$$

$$P=\frac{1}{f}=\frac{1}{0.24\ \text{m}}=4.2\ \text{D}.$$

Answer The power of the convex lens is 4.2 D, and the image is 0.48 m to the left of the lens.

EXAMPLE 16.5 An object 0.20 m high is placed perpendicular to the principal axis at a distance of 0.6 m from a concave lens of focal length 0.4 m. Find the position and the height of the image.

Graphical solution Let the scale of Fig. 16.19 be 1 cm = 0.1 m. Follow the steps (a), (b) and (c) of Example 16.3.

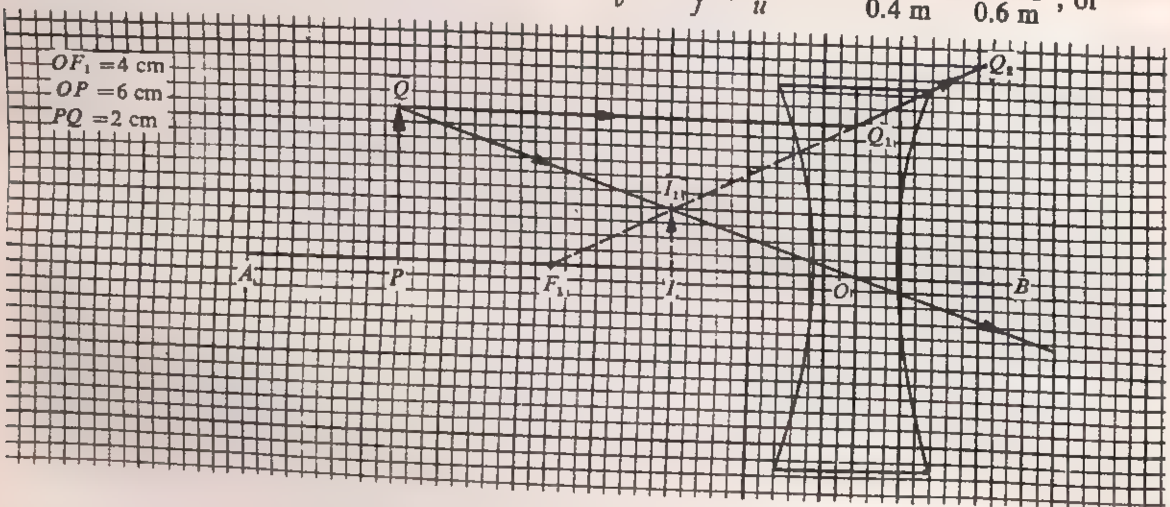


FIG. 16.19 Example 16.5.

(a) In a concave lens the primary focus is to the left of the lens. Hence mark a point F_1 on AB such that $OF_1 = 4$ cm (focal length = 0.4 m).

(b) At a distance of 6 cm from O (object at a distance of 0.6 m) draw a line PQ 2 cm high (object is 0.2 m high) perpendicular to the principal axis.

(c) QQ_1 is a line parallel to AB, and represents an incident light ray parallel to the principal axis. After refraction through the lens it must pass through F_1 when produced backwards. Hence Q_1Q_2 is the refracted ray.

(d) An incident light ray QO passing through the optical centre goes undeviated.

(e) Drop a perpendicular from I_1, the point of intersection of OQ and Q_1Q_2 produced backwards, on AB. II_1 is the virtual image of the object PQ. In Fig. 16.19, $II_1 = 0.8$ cm. Hence,

Image height $= 0.8\times 0.1$ m $= 0.08$ m.

In Fig. 16.19, $OI = 2.4$ cm. Hence,

Image distance from the lens $= 2.4\times 0.1$ m $= 0.24$ m.

Analytic method $u = -0.6$ m and $f = -0.4$ m. The lens formula gives,

$$\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$$

$$\frac{1}{v}=\frac{1}{f}+\frac{1}{u}=-\frac{1}{0.4\ \text{m}}-\frac{1}{0.6\ \text{m}},\ \text{or}$$

$v = -0.24$ m ($-$sign indicates that the image is to the left of the lens)

$$m=\frac{v}{u}=\frac{-0.24\ \text{m}}{-0.6\ \text{m}}=0.4$$

(+sign indicates that the image is virtual)

Height of the image = magnification $\times$ height of the object

$= 0.4\times 0.2$ m $= 0.08$ m.

Answer The erect image is 0.24 m to the left of the lens and is of height 0.08 m.

EXAMPLE 16.6 Where should an object be placed in front of a convex lens of focal length 0.2 m such that magnification is unity?

Solution $f = 0.2$ m and $m = v/u = -1$, or, $v = -u$. From the lens formula,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} = -\frac{1}{u} - \frac{1}{u} = -\frac{2}{u}, \text{ or}$$

$$u = -2f = -2 \times 0.2 \text{ m} = -0.4 \text{ m}.$$

Answer The object should be placed 0.4 m to the left of the convex lens.

EXAMPLE 16.7 The distance between a candle and a screen is 90 cm. A convex lens of focal length 20 cm is placed such that the reduced image of the candle is formed on the screen. Find out the position of the lens.

Solution $f = 20$ cm $= 0.2$ m and the distance between image (screen) and the object (candle) is 90 cm or 0.9 m. Let the distance between object and lens be y. Hence the distance between image and the object $= v + y$.

$$v + y = 0.9 \text{ m, or}$$

$$v = 0.9 \text{ m} - y.$$

Also $$u = -y.$$

From the lens formula,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u},$$

$$\frac{1}{0.2 \text{ m}} = \frac{1}{0.9 \text{ m} - y} + \frac{1}{y}, \text{ or}$$

$$\frac{1}{0.2 \text{ m}} = \frac{y + 0.9 - y}{(0.9 \text{ m} - y)\, y} = \frac{0.9 \text{ m}}{(0.9 \text{ m} - y) y}$$

or, $$0.9 \text{ m}\, y - y^2 = 0.9 \text{ m} \times 0.2 \text{ m}$$

or, $$y^2 - 0.9 \text{ m}\, y + 0.18 \text{ m}^2 = 0.$$

or, $$(y - 0.6 \text{ m})(y - 0.3 \text{ m}) = 0.$$

or, $$y = 0.6 \text{ m or } 0.3 \text{ m}$$

$$u = -0.6 \text{ m or } -0.3 \text{ m}.$$

This implies that the image of the candle will be formed on the screen for two positions of the lens. If the lens is placed 60 cm from the object, a reduced image will be formed. In the other case, when the lens is at a distance of 30 cm from the object, an enlarged image will be formed.

Answer The convex lens should be placed 60 cm away from the object.

EXAMPLE 16.8 What is the power of a lens of focal length 50 cm?

Solution $f = 50$ cm $= 0.5$ m.

$$P = \text{power} = \frac{1}{f} = \frac{1}{0.5 \text{ m}} = 2\text{D}.$$

Answer The power of the lens is 2 D.

PROBLEMS

16.1 Show with the help of the lens formula that the primary and the secondary focal lengths are equal in magnitude but have different signs. Do this for concave and convex lenses.

16.2 Suppose we place a convex lens of focal length 50 cm in between a screen and the sun. How far should the screen be from the lens in order to form a sharp image of the sun on the screen?

16.3 Determine the power of convex lenses of focal length 20 cm, 40 cm and of concave lenses of focal length 10 cm, 50 cm and 75 cm.

16.4 An object of height 5 cm is placed at right angles to the principal axis, 60 cm from a convex lens of focal length 20 cm. Determine the position, height of the image and magnification.

16.5 A finger of height 5 cm is placed perpendicular to the principal axis, 40 cm from a convex lens of focal length 30 cm. Find the position, nature and height of the image.

16.6 A candle of height 6 cm is placed 27 cm from a convex lens of focal length 36 cm. Find the position, nature and height of the image.

16.7 A pencil placed in front of a convex lens produces a virtual image twice the size of the object. Determine graphically the power of the lens, when the image is at a distance of 20 cm from the lens.

16.8 An object 4 cm high is placed at right angles to

the principal axis and is 1.2 m away from a concave lens. If the focal length of the lens is 40 cm, determine the position, nature and height of the image.

16.9 An object 4 cm high is placed in front of a convex lens. An image of height 8 cm is formed 20 cm on the other side of the lens. Find the focal length of the lens.

16.10 A convex lens of focal length 20 cm forms a real image 40 cm away from the lens. What is the object distance?

16.11 An image of a bulb is obtained on a screen which is 120 cm from a convex lens. If the object is 40 cm away from the lens, determine the focal length of the lens.

16.12 A concave lens of power—5D produces an image 0.6 m from the lens. Find the position of the object.

16.13 In a concave lens if the object and image distances are 120 cm and 40 cm respectively, determine the focal length of the lens.

16.14 An object is placed 100 cm from a convex lens of focal length 25 cm. Determine graphically the position of the image.

16.15 What is the size and nature of the image of an object of height 6 cm, placed 25 cm to the left of a convex lens when the image is (i) 50 cm to the left of the lens, (ii) 50 cm to the right of the lens?

16.16 Determine the magnification when the object is 0.01 m high and the image is (i) 0.05 m high and inverted, (ii) 0.02 high and upright.

16.17 Find out the magnification if the image formed by a concave lens is 0.02 m high. The height of the object is 0.04 m.

16.18 If a convex lens produces an image of length 0.01 m of an object of 0.03 m, determine the magnification.

16.19 The image formed by a lens is one-third the object size. What is the magnification if the image is (i) real, (ii) virtual?

16.20 If the image is magnified four times, determine the magnification when the image is (i) real, (ii) virtual.

16.21 Find out the position of the object if its two times magnified image is formed 0.2 m to the right of the lens.

16.22 A concave lens produces an image one-fourth the size of the object. Find the position of the image if the object is 40 cm from the lens.

16.23 Where should a convex lens of focal length 16 cm be placed to obtain a four times magnified (i) virtual, (ii) real image of the object?

16.24 An object is placed 0.6 m in front of a convex lens. If the image is half the object size, determine the focal length of the convex lens.

16.25 How far should a candle be placed from a convex lens of power 2.5 D so that its image is one-fourth the size of the object. Determine the image distance.

16.26 What will be the power of a concave lens if it produces an image of one-third the object size? The object is 40 cm in front of the lens.

16.27 A convex lens of focal length 20 cm is placed 28 cm away from a wall. How far should an object be placed from the lens, so as to form its real image on the wall?

17 Optical Instruments

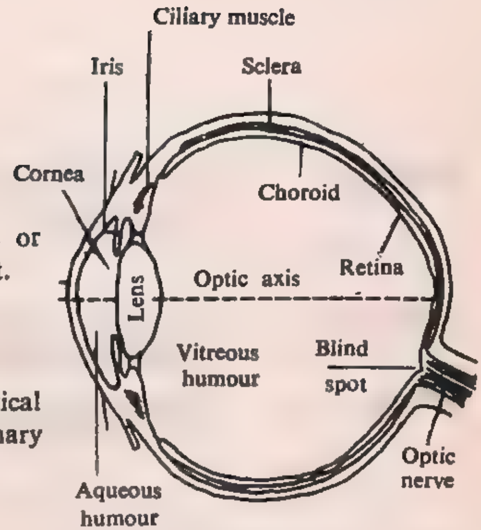


FIG. 17.1 Schematic diagram of the human eye.

D.17.1 Optical Instrument A device made of curved mirrors or lenses to produce, record, and analyse the image of an object.

17.1 THE EYE

D.17.2 Eye One of the most sensitive and sophisticated optical instrument devised by nature. It is a remarkable evolutionary achievement of nature.

FUNCTIONAL ASPECTS OF EYE

TABLE 17.1 Parts of the eye and their functions.

Name of part	*Description*	*Function*	*Remarks*
Eyeball	Spherical enclosure of diameter$\sim$2.5 cm.	To house all the parts of the eye.	
Sclera	Outer hard coating of eyeball.	To maintain shape of the eyeball.	
Choroid	Middle layer of eyeball containing a dark pigment.	To supply blood, oxygen and food to the various parts of the eye. Dark pigment absorbs unwanted light which could blurr the image.	
Retina	Innermost layer of eyeball having photoreceptors.	To provide a surface for the formation of image.	

Name of part	*Description*	*Function*	*Remarks*
Rods and cones	Photoreceptors.	To convert the image into a series of electrical signals for transmission to the brain.	Rods, 0.1 mm in diameter, 2.8 mm long, $\sim 1.2 \times 10^8$ in number. Cones $\sim 6.5 \times 10^6$. Rods work in dim light. Cones work in bright light. Cones distinguish colours, rods do not.
Blind spot	Portion of retina with no photoreceptors.	A junction of optic nerves, which transmit electric signal to the brain.	If light falls here it is not detected.
Yellow spot	Portion of retina having only densely packed cones.		~ 0.2 mm from centre of retina.
Cornea	Transparent portion of sclera in front of eye.	To allow light to enter the eyeball.	Most of the bending of light takes place here ($R \sim$ 8 mm). In action a convex lens of power $\sim +44$D.
Iris	Coloured ring behind the cornea.	To control the amount of light entering the eye.	
Pupil	Circular opening in iris.	To allow light to enter the eye.	In dim light diameter ~ 6 mm, in bright light ~ 1.5 mm, for normal vision ~ 5 mm.
Lens	Biconvex crystalline lens of variable focal length.	To form image on retina.	~ 3 mm from cornea, ~ 17 mm from retina. Power ~ 15 D, in air its power ~ 150 D.
Aqueous humour and vitreous humour	The water-like liquid of refractive index 1.336 between lens and cornea, and between lens and retina.		

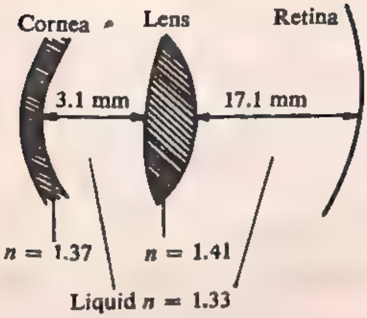


FIG. 17.2 The optical components of a human eye.

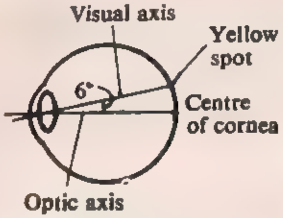


FIG. 17.3 Optic and visual axis. The angle between visual axis and optic axis is 6°.

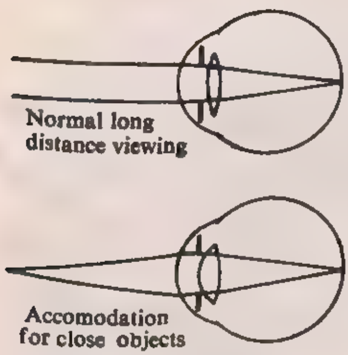


FIG. 17.4 Accomodation. The eye is able to focus very far as well as near by objects by changing the radii of curvature of the lens surface.

D.17.3 Reduced Eye A representation of the eye, obtained by replacing the various refractive surfaces (e.g. cornea, aqueous humour, eye lens and vitreous humour) by a single lens, of approximate power 59 D when adjusted at the far point, and placed at a distance of 17 mm in front of the retina.

NOTE This representation is useful for the study of optical functioning of the eye.

D.17.4 Near Point The closest point at which the object can be seen clearly by the normal eye.

TYPE OF QUANTITY Scalar

SPECIFICATION For a normal adult it is 25 cm.

NOTES (i) For children it is less than 25 cm.

(ii) In some kinds of eye defects it is greater than 25 cm (D. 17.12).

D.17.5 Far Point The farthest point from the normal eye which can be seen clearly.

TYPE OF QUANTITY Scalar

SPECIFICATION For a normal adult it is at a very large distance (at infinity).

NOTE In some kinds of eye defects (D.17.11) it is much less than infinity.

D.17.6 Normal Vision (Emmetropia) The condition of vision in which the far point is at infinity and the near point is at 25 cm.

D.17.7 Optic Axis An imaginary line joining the centre of the cornea to the optical centre of the eye lens.

NOTE Optic axis is same as the principal axis of the reduced eye.

D.17.8 Visual Axis An imaginary line joining the yellow spot and the optical centre of the eye lens.

NOTE The vision is best if light travels along this axis.

D.17.9 Power of Accomodation The ability of the eye lens to change its focal length to view objects at different distances.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION A

SPECIFICATION The difference between the powers of the eye lens for focussing near and distant objects. Measured in dioptres (D).

MATHEMATICAL EXPRESSION For an object at a distance u from the eye lens, the image is formed at the retina at a distance v from the eye lens. The power of the eye lens is

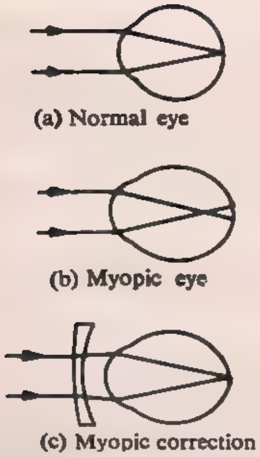


FIG. 17.5 Myopia. (a) An eye defect in which the eyeball becomes elliptical with major axis along optic axis (elongated). (b) The object at a large distance is focussed in front of the retina and hence the image on the retina is blurred. (c) The object is again focussed on the retina if a concave lens is placed in front of the eye.

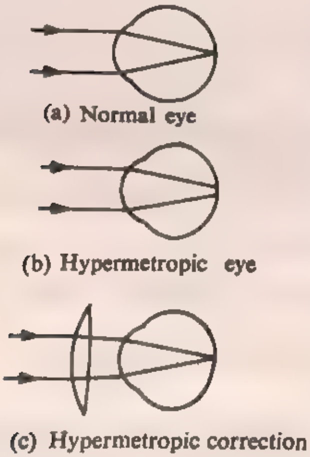


FIG. 17.6 Hypermetropia. (a) The eye defect in which the eye ball becomes elliptical with minor axis along optic axis. A point source at the near point is focussed behind the retina. The image on the retina is a blurred circular patch. (c) The object is again focussed if a convex lens is placed in front of the eye.

$$P_f = \frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$P_\infty = \frac{1}{v}, \text{ since for far point } u = \infty.$$

$$P_{near} = \frac{1}{v} - \frac{1}{0.25\text{ m}}, \text{ since for near point } u = 0.25\text{ m}$$

$$A = P_\infty - P_{near} = \frac{1}{v} - \frac{1}{v} + \frac{1}{0.25\text{ m}} = 4\text{D}.$$

NOTES (i) A for children is much larger as their near point is less than 0.25 m.

(ii) A decreases with age. For children it is about 14D while at the age of 45 years, it is approximately 2D.

D.17.10 Persistence of Vision The property of the eye by virtue of which the sensation of vision remains for a short time even after the object being viewed is removed.

NOTE This property is used in making moving pictures.

DEFECTS OF THE EYE

D. 17.11 Short Sight (Myopia) A defect of the eye in which a person can see *near objects clearly* but the *objects at a distance appear blurred.*

CAUSE The eyeball is too long. As a consequence, the light from a distant object is focussed in front of the retina.

REMEDY It is corrected by placing a concave lens in front of the eye. See Fig. 17.5.

NOTE The far point in such a case is not at infinity.

D.17.12 Long Sight (Hypermetropia) A defect of the eye in which a person can see *distant objects clearly* but *nearer objects appear blurred.*

CAUSE The eyeball is too short. As a consequence the light from a near object is focused behind the retina.

REMEDY It is corrected by placing a convex lens in front of the eye. See Fig. 17.6.

NOTE The near point in such a case is farther than 25 cm.

D. 17.13 Astigmatism A defect of the eye in which a person can clearly see horizontal lines but not vertical lines.

CAUSE Either due to differences in curvature of the different parts of the cornea or a slight tilting of the crystalline lens of the eye.

REMEDY By using a cylindrical lens before the eye.

D. 17.14 Presbyopia A defect of the eye in which the near point of the eye recedes beyond the convenient reading distance.

CAUSE In old age, the ciliary muscles become weak or the crystalline lens of the eye loses its elasticity and hardens.

REMEDY By using a convex as well as a concave lens (bifocal lenses). The convex lens helps the eye to see objects at large distance while the concave lens helps it to see near objects.

NOTES (i) In such a case, the power of accomodation is greatly lost.

(ii) In this defect, the eye remains more or less permanently focused at a constant distance.

17.2 THE CAMERA

D. 17.15 Lens Camera (*or, simply, Camera*) An attempted man-made copy of the eye. See Fig. 17.7.

NATURE OF IMAGE Much smaller than object, real and inverted.

NOTES (i) The size of the image depends on the focal length of the lens. The magnification increases as the focal length of the lens increases.

(ii) In an actual camera a converging lens is made by combining several lenses; individual lenses may be convex or concave. The combination helps to remove some of the defects found in an image formed by a single lens.

(iii) In good cameras, the lens is the most expensive item.

SOME CONCEPTS ASSOCIATED WITH CAMERA WORKING

FIG. 17.7 Camera. An attempted man made copy of the eye. A reduced image of the object is obtained on a film which makes a permanent record of the event. The object is focussed on the film by changing the distance between the lens and film by a focussing arrangement. When the shutter lever is pressed, the shutter opens for a predetermined time, during which light is allowed to affect the film.

TABLE 17.2 Parts of the camera and their functions.

Part	*Description*	*Function*
Light tight box	A light tight rectangular black box painted black from inside.	Not to allow any light except through lens to enter the camera.
Lens	A converging lens of fixed focal length.	To form an image of the object on the film.
Diaphragm	An opaque plate, with a variable circular opening, between lens and film.	To vary the aperture of the lens.
Film	A role of celluloid having a layer of photo-sensitive material like silver chloride.	To obtain a permanent record of the object image.
Aperture	Circular opening in the diaphragm.	To control the amount of light entering the camera.
Shutter	An arrangement between lens and film.	To control the time for which light can fall on the film.
Focusing arrangement	An arrangement to change the distance between lens and film.	To bring the near and distant objects in focus on the film.
Exposure meter	A light sensitive meter.	To determine the correct exposure time.

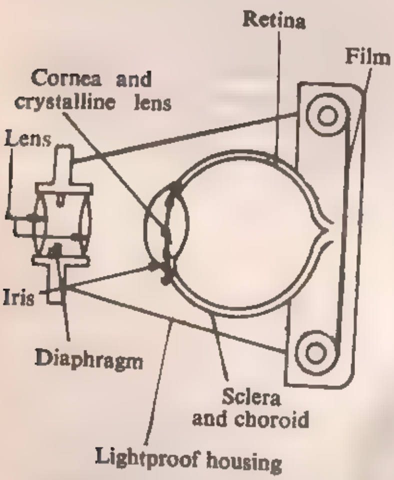


FIG. 17.8 Some points of similarity between the eye and the camera.

TABLE 17.3 Comparison between eye and camera.

Similarities Both have:

(i) Converging lens system.

(ii) Variable aperture system (iris in eye, diaphragm in camera).

(iii) Light sensitive surface (retina in eye, photo film in camera).

(iv) Light absorbing coating (choroid in eye, black paint in camera).

(v) Protector (sclera in eye, metal or plastic box in camera).

(vi) Magnification less than 1.

(vii) Image real and inverted.

Differences

(i) Eye lens is of variable focal length while the lens in a camera is of fixed focal length. (Now lenses of variable focal lengths, known as *zoom lenses*, are also available.)

(ii) The distance between the eye lens and retina is fixed. In the camera, the distance between the lens and film is variable.

(iii) Retina has persistence of vision. Film does not have this property.

(iv) Normal eye is free from all defects. The camera lens has some defects such as spherical aberration, and different focal lengths for rays of different wavelength.

D. 17.16 f-Number A measure of the amount of light entering the camera.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION f-number

SPECIFICATION The ratio of focal length of the lens and diameter of the aperture. Usually marked on the camera as a series of numbers: 1.7, 2, 2.8, 4, 5.6, 8, 11, 16, 22.

MATHEMATICAL EXPRESSION

$$f\text{-number} = \frac{\text{focal length}}{\text{aperture diameter}} = \frac{f}{d}$$

NOTE Amount of light entering the camera $\propto$ (aperture diameter)^2, or $I \propto d^2$.

$$\frac{I_1}{I_2} = \left(\frac{d_1}{d_2}\right)^2 = \left(\frac{f_2\text{-number}}{f_1\text{-number}}\right)^2$$

If f_1-number $= 2.8$ and f_2-number $= 4$,

$$\frac{I_1}{I_2} = \left(\frac{4}{2.8}\right)^2 = 2, \text{ or } I_1 = 2I_2.$$

Thus f-2.8 allows twice as much light to pass through the aperture as f-4 would. One higher f-number decreases the amount of light to half and vice versa.

D. 17.17 Shutter Speed – Time of Exposure The duration for which the shutter remains open. Usually marked on a camera as $n = 1, 2, 4, 8, 15, 30, 60, 125, 250, 500, 1000$. The shutter speed is $(1/n)$s.

D. 17.18 Depth of Field A measure of the range of distance in front of a camera, the objects within which are in focus.

NOTE The depth of field depends on f-number. Higher the f-number, greater will be the depth of field.

D. 17.19 Film Speed A measure, under standard light conditions, of how quickly the film will be correctly exposed.

17.3 PROJECTOR

D. 17.20 Projector An optical instrument to produce an enlarged image of a transparent small size object on a white screen.

CONSTRUCTION See Fig. 17.9.

WORKING Light from a powerful source is concentrated uniformly by a condenser lens on the negative of a film or the slide

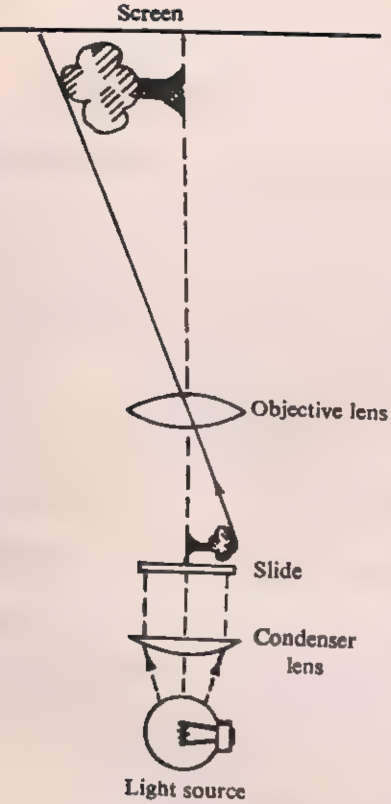


FIG. 17.9 Projector. An optical instrument opposite in action to the camera. Light from the source is condensed on a film contained in a slide carrier. Since the film is between F and $2F$ of the projector lens (converging) an enlarged image is formed on the screen.

TABLE 17.4 Parts of the projector and their functions.

Part	*Description*	*Function*
Source of light	Usually a carbon lamp.	To give an intense beam of light.
Reflector	Parabolic or concave mirror behind the source of light.	To concentrate light in the forward direction.
Condenser	A system of converging lenses (usually two plane convex lenses).	To concentrate light uniformly on the slide.
Heat filter		To absorb heat energy from the light rays to protect the film from damage.
Slide holder	A metallic frame.	To hold the slide.
Projection lens	A converging lens of small focal length mounted on a moveable screw head.	To form the image of the slide on a white screen.

NOTE The light source is very close to the focus of the reflector as well as the focus of the condenser.

to be shown. The object is placed between F and $2F$ of the projection lens but very close to F. Since the slide is very close to F, a real, inverted and enlarged image is formed on the white screen. To produce an upright image, the slide itself is kept upside down. The image is focussed by changing the distance between the lens and the slide.

17.4 MICROSCOPE

Combinations of lenses can be used to produce a variety of optical instruments, one of them being the microscope used to study minute objects not visible to the naked eye. Cells in a living organism were discovered by a simple converging lens used as a magnifier.

D. 17.21 Microscope An instrument which produces an enlarged image of a very small object placed close to the instrument.

NOTES (i) By *very small object* we mean an object which cannot be seen at all or cannot be seen clearly by the unaided eye.

(ii) The small object is usually kept within a few centimetres of the microscope.

(iii) A microscope may be an optical one (using light to produce the image), or an electron microscope (using electrons to produce the image). Here we shall deal only with simple and compound optical microscopes.

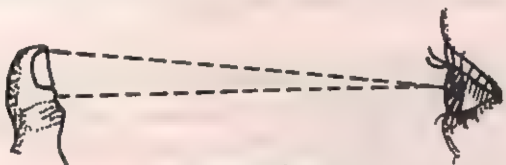
D. 17.22 Simple Microscope (*Magnifying glass*) An optical microscope with a single lens to produce an enlarged image of a small object.

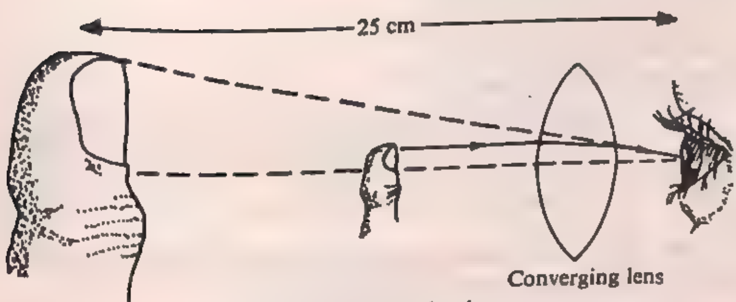
CHARACTERISTICS See Table 17.6.

NOTES (i) A simple microscope has to be a convex lens.

(ii) The primary focal length of the convex lens should be small.

(iii) The maximum magnification obtained without any distortion in the image is about 5.


(a) Without lens



(b) By simple converging lens

FIG. 17.10 Simple microscope. A magnifying glass (converging lens) which produces a magnified, virtual, erect image 25 cm away from the eye lens.

D. 17.23 Objective A lens system in an optical instrument which is close to the object.

FUNCTION To produce a magnified image of the object.

NOTES (i) Its focal length and magnification are denoted by f_o and m_o respectively.

(ii) Normally, in order to remove various defects from the image, the eye piece and objective are constructed by combining several lenses, which may be convex or concave.

D. 17.24 Eye Piece A lens system in an optical instrument which is close to the eye.

FIG. 17.11 Compound microscope. A magnifier made from two converging lenses. The objective has a short focal length and the eyepiece a large focal length. The object is placed between F and $2F$ of the objective, but very close to F. A real inverted image is formed before the eyepiece. The final image is virtual, inverted and 25 cm away from the eye lens. The magnification is much greater than that of a simple microscope. One can easily achieve a magnification of about 1100.

FUNCTION To magnify the image formed by the objective.

NOTE Its focal length and magnification are denoted by f_e and m_e respectively.

D. 17.25 Compound Microscope An optical microscope with an arrangement of at least two lens systems.

CONSTRUCTION See Fig. 17.11.

CHARACTERISTICS See Table 17.6.

17.5 TELESCOPE

A telescope is a lens system to observe distant objects. The first telescope was made by Galileo in 1609. It helped him to discover that the surface of the moon is not smooth and that the planet Jupiter has moons like our earth. Astronomy is impossible without this instrument. Telescopes are widely used in the scientific world, by bird watchers, etc.

D. 17.26 Angular Magnification The ratio between the angle subtended at the eye by the image and the angle subtended at the eye by the object when seen directly.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION m_a

SPECIFICATION No units

MATHEMATICAL EXPRESSION

$$m_a = \frac{\text{Angle subtended by the image at the eye}}{\text{Angle subtended by the object at the eye}} = \frac{\beta}{\alpha} \qquad (E.17.1)$$

NOTE D. 15.19 is inadequate in the study of telescopes because h_i/h_o is nearly zero for the objective.

D. 17.27 Telescope An optical instrument for producing a magnified image of a distant object.

TABLE 17.5 Comparison between microscope and telescope. (For other similarities and dissimilarities see Table 17.6)

	Microscope	*Astronomical telescope*
1. Objective diameter	Small	Large
2. Eyepiece diameter	Large	Small
3. Objective focal length	Very small	Very large
4. Eyepiece focal length	Large	Small

TABLE 17.6 Some characteristics of telescopes and microscopes.

Instrument	*Position of object*	*Image by the objective (same as object for eyepiece)*	*Final image (image by eyepiece)*	*Distance between objective and eyepiece*	*Magnification*
Simple microscope	Between O and F	Virtual, erect, 25 cm from eye	—	—	$m = 1 - \frac{v}{f} > 1$
Compound microscope	Between F and $2F$ of objective but very close to F	Real, inverted, between F and O of eyepiece but very close to F	Virtual, inverted, 25 cm from eye	Slightly less than $f_o + f_e$ ($f_e > f_o$ and f_o very small)	$m = m_o m_e \gg 1$
Astronomical telescope	At infinity	Real, inverted, at the focus of eyepiece	Real, inverted, at infinity	$f_o + f_e$ ($f_o > f_e$ and f_o very large)	$m = \frac{f_o}{f_e} > 1$
Galilean telescope	At infinity	Real, inverted	Virtual, erect, between objective and eyepiece	$f_o - f_e$ ($f_o > f_e$)	$m = \frac{f_o}{f_e}$, rarely greater than 6

NOTE As the magnification increases the image size also increases. The diameter of the objective, therefore, should be *large* to gather enough light to make the image visible. In contrast a microscope objective has a *small* diameter.

D. 17.28 Reflecting Telescope An optical telescope having a concave mirror, usually paraboloid, of large focal length for collecting light.

CONSTRUCTION See Fig. 17.12.

CHARACTERISTICS See Table 17.6.

NOTES (i) A paraboloid concave mirror is used because it does not produce any aberration, including spherical aberration.

(ii) Modern astronomical telescopes are invariably of this kind.

(iii) The largest reflecting telescope has a concave mirror of diameter 508 cm (~ 5.1 m) at Mt. Palomar, California, U.S.A.

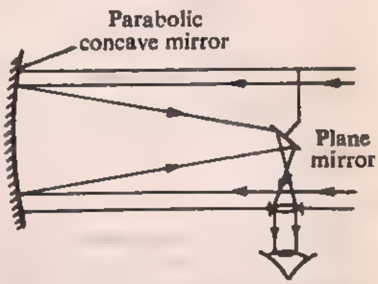


FIG. 17.12 Reflecting telescope. An optical instrument in which a concave mirror is used instead of a lens. This type of telescope is superior to the refracting type because loss of light is less in reflection than in refraction.

D. 17.29 Refracting Telescope (*or, simply, Telescope*) An optical instrument consisting essentially of two lens systems. The objective is a converging lens system of long focal length and the eye piece is a converging lens system of short focal length.

CONSTRUCTION See Fig. 17.13.

NOTES (i) This type of telescope is not used for accurate scientific work because a lens system is never free from aberrations.

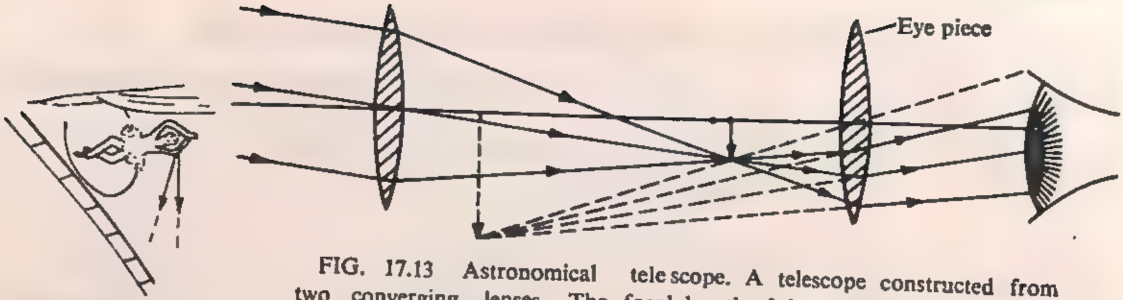


FIG. 17.13 Astronomical telescope. A telescope constructed from two converging lenses. The focal length of the objective is much greater than that of the eyepiece.

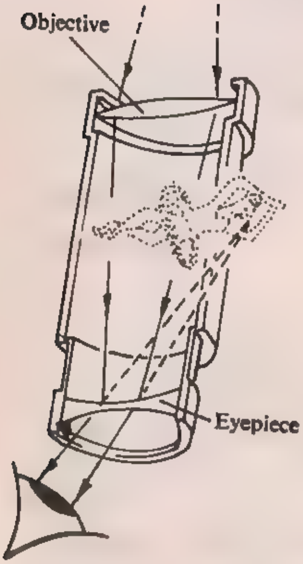


FIG. 17.14 Galilean telescope. The eyepiece is a concave lens. The final image is upright and virtual.

(ii) There is a limit to the diameter of the objective lens system. Beyond this limit, glass distorts under its own weight.

(iii) In the world, the biggest refracting telescope has a diameter of 101.6 cm and a focal length of 1981.2 cm at Yerkes Observatory, Wisconsin, U.S.A.

The various types of telescopes are discussed below.

(a) ***Astronomical (Kepler) Telescope***

CONSTRUCTION See Fig. 17.13.

WORKING CHARACTERISTICS See Table 17.6.

LIMITATIONS The final image is inverted, hence it cannot be used to view objects on the earth. However, in viewing stars this does not cause any problem as there is no meaning of up and down for a star.

(b) *Galilean Telescope*

CONSTRUCTION See Fig. 17.14.

WORKING CHARACTERISTICS See Table 17.6.

(c) *Terrestrial Telescope*

CONSTRUCTION See Fig. 17.15.

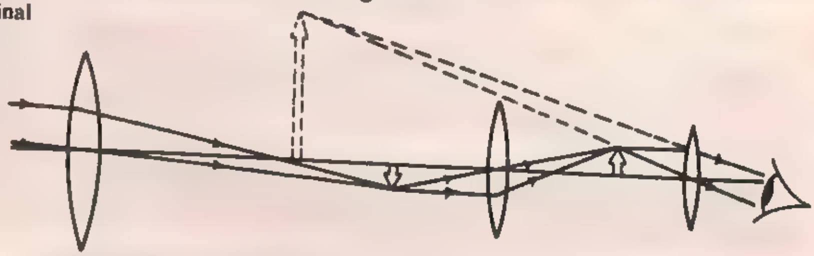


FIG. 17.15 Terrestrial telescope. A telescope similar to an astronomical telescope except that a converging lens is placed between the objective and eyepiece so that the image produced is real and upright.

SOLVED EXAMPLES

EXAMPLE 17.1 The power of the eye lens is not constant. The power is changed by altering the radii of curvature of the two lens surfaces. For most normal adult persons it varies between 60

D and 68 D. What are the corresponding focal lengths? Is the eye lens converging or diverging?

Solution We know that focal length in metres = 1/power in dioptres.

$$f \text{ corresponding to } 60\text{ D} = \frac{1}{60\text{ D}} = 0.017\text{ m}.$$

$$f \text{ corresponding to } 68\text{ D} = \frac{1}{68\text{ D}} = 0.015\text{ m}.$$

By convention the positive focal length (or positive power) means that the lens is converging.

Answer The eye lens is a converging lens. Its focal length varies between 0.017 m and 0.015 m.

Example 17.2 Most of you must have seen a camera. In a negative taken by a 35 mm camera containing a converging lens of focal length 0.05 m, the height of a man is 0.035 m. If the actual height of the man is 1.75 m, determine the distance of the man and film from the lens.

Solution $f = 0.05$ m

$$m = \frac{\text{height of man in negative}}{\text{actual height of man}}$$

$$= -\frac{0.035\text{ m}}{1.75\text{ m}} = -0.02.$$

(negative sign because the image formed by a convex lens is real)

$$m = \frac{v}{u}, \text{ or } v = mu = -0.02\,u.$$

From the lens formula,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{-0.02\,u} - \frac{1}{u} = \frac{-1.02}{0.02u}$$

or, $$u = \frac{-0.05\text{ m} \times 1.02}{0.02} = -2.55\text{ m}$$

$$v = -0.02 \times (-2.55\text{ m}) = 0.051\text{ m}.$$

Answer The man is 2.55 m in front of the lens and the film is 0.051 m behind the lens.

Example 17.3 A magnifying glass is of 5.0 cm focal length. What will be the magnification produced by it?

Solution $f = 5$ cm $= 0.05$ m. In a magnifying glass a virtual image is formed 25 cm away from the lens. Hence, $v = -0.25$ cm.

$$m = \frac{v}{u} = 1 - \frac{v}{f} = 1 - \frac{-0.25\text{ m}}{0.05\text{ m}}$$

$$= 6.$$

Answer The magnification produced by the magnifying glass is 6.

Example 17.4 A boy interested in collecting postage stamps has a simple microscope. When he holds it above a stamp, the image formed is three times the size of the stamp. Determine the focal length of the lens. What is the distance of the image and the stamp from the lens?

Solution The magnification of the simple microscope is

$$m = 1 + \frac{0.25\text{ m}}{f}$$

or $$f = \frac{0.25\text{ m}}{m-1}.$$

According to the question $m = 3$. Hence,

$$f = \frac{0.25\text{ m}}{3-1} = 0.125\text{ m}.$$

The image is virtual and is formed, in the case of a simple microscope, at a distance of 0.25 m from the lens on the same side as the stamp.

$$u = \frac{v}{m} = \frac{-0.25\text{ m}}{3} = -0.083\text{ m}.$$

Answer The focal length of the simple microscope is 0.125 m. The image is formed 0.25 m from the lens on the same side as the stamp. The stamp is 0.083 m from the lens.

Example 17.5 The magnifying power of a compound microscope is 25. It is found that the objective and eyepiece magnify the image equally. Determine the magnifying power of the objective.

Solution Magnifying power of the objective = magnifying power of the eyepiece, or $m_o = m_e$. Magnifying power of the compound microscope $= m_o \times m_e = m_o^2$.

$$m_o^2 = 25 \text{ or } m_o = 5.$$

Answer The magnifying power of the objective is 5.

EXAMPLE 17.6 A bird sitting on the top of a tree subtends an angle of 5′ at the eye. The bird is now seen with the help of a telescope. The image in the telescope subtends an angle of 1° at the eye. What is the magnifying power of the telescope?

Solution

$$\text{Magnifying power} = \frac{\text{angle subteneded by the image at the eye}}{\text{angle subtended by the bird at the eye}}$$

$$= \frac{60'}{5'} = 12.$$

Answer The magnifying power of the telescope is 12.

EXAMPLE 17.7 You are given two convex lenses of focal length 0.1 m and 0.3 m respectively. How will you construct an astronomical telescope from these two lenses? What will be its magnifying power?

Solution A telescope is an instrument used for viewing distant objects. It forms a magnified image of these objects. Its magnification must be greater than 1.

$$m = \frac{\text{focal length of the objective}}{\text{focal length of the eyepiece}} = \frac{f_o}{f_e}.$$

Since $m > 1, f_o > f_e$. We are given two lenses of focal length 0.1 m and 0.3 m. The lens of focal length 0.3 m should be used as the objective and the lens of focal length 0.1 m as the eyepiece.

In the astronomical telescope distance between objective and eyepiece $= f_o + f_e = 0.4$ m. Therefore, eyepiece should be 0.4 m away from the objective.

$$m = \frac{f_o}{f_e} = \frac{0.3 \text{ m}}{0.1 \text{ m}} = 3.$$

Answer The lens of focal length 0.3 m should be used as objective and the lens of focal length 0.1 m should be used as eyepiece. The distance between objective and eyepiece should be 0.4 m. The magnification of such a telescope will be 3.

PROBLEMS

17.1 What should be the power of an eye lens so that a real image of an object 25 cm from the lens is formed on the retina 17 mm from the lens? What is the magnification?

17.2 A convex lens is used as a simple microscope. The maximum magnification power of such a microscope is about 30. What is the focal length of a convex lens giving such a magnifying power?

17.3 What will be the magnifying power of a simple microscope if the focal length of the convex lens is 5 cm. Find out the distance of the object and image from the lens.

17.4 The power of a child's eye lens varies between 60D and 74D. Determine the corresponding focal lengths.

17.5 The focal length of the eyepiece of an astronomical telescope having a magification of 4, is 5 cm. Determine the focal length of the objective and the distance between the eyepiece and objective.

17.6 An object subtends an angle of 4 minutes at the eye. This object is magnified two times when viewed by an astronomical telescope. Determine the angle subtended by the image at the eye.

17.7 In a compound microscope, the magnifying power of the eyepiece is 2 and that of the objective is 10. What will be the magnifying power of the compound microscope?

18 Electrostatics, Current and Potential Difference

The word electricity is the Greek name for amber, a yellowish resin, which attracts light objects such as small pieces of dry grass, thread, pith, etc. when it is rubbed with silk. From about 5th century B.C. to 19th century A.D., the study of electricity confined itself to the forces between two charged bodies. Only in the 19th century A.D. was the study extended to include effects of moving charges. Since then it has taken tremendous strides, and today we cannot imagine a life without electricity. The list of items which run on electricity is endless. Even biological systems such as the nervous system, the brain, the heart, etc. work on electrical impulses.

18.1 BASIC CONCEPTS OF ELECTROSTATICS

The study of electricity is divided into two parts.

Electrostatics deals with the concept of electric charge and properties of stationary charged bodies. (The duplicating technique, xerox, relies on electrostatics.)

Electrodynamics deals with moving charged bodies and their effects.

D. 18.1 Elementary Particles The basic units of which all matter is composed.

EXAMPLES Protons, neutrons, electrons.

D. 18.2 Electric Charge A basic property of some elementary particles, due to which these particles can exert a force (called the electric force) on other charged elementary particles at a distance.

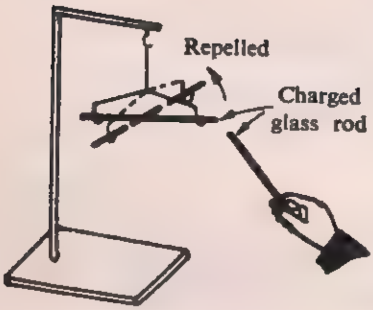
TYPE OF QUANTITY Scalar.

WRITTEN REPRESENTATION q, Q

SPECIFICATION Magnitude measured in Coulomb (C). See D.18.5. Sign either negative or positive.

NOTES (i) Elementary particles are the 'source' of all electric charge. When a large body, like a metallic sphere, is electrically charged, it contains billions of elementary particles (usually electrons or protons) whose charges act together to produce an electrical effect.

(ii) There are two types of electric charges : *negative* charge (the kind of charge on an electron) and *positive* charge (the kind of charge on a proton). Historically, the charge acquired by a glass rod after it is rubbed with silk, was defined as positive. Negative charge was the one which an ebonite rod acquired on rubbing with fur. Charging a body by rubbing is known as *electrification* by friction. These positive and negative conventions are purely arbitrary but nevertheless useful.



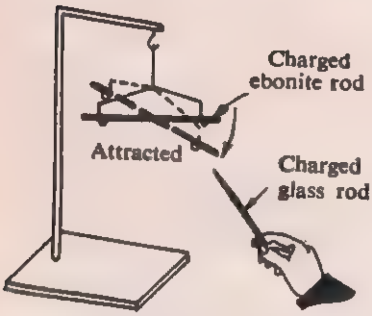


FIG. 18.1 Experiment with charged bodies. (a) A glass rod charged by rubbing with silk is suspended to rotate freely. When another charged glass rod is brought near it, the suspended rod moves away: i.e. the two glass rods repel each other. (b) The same thing is noticed with charged ebonite rods. (c) A charged ebonite rod is brought near a suspended glass rod. The glass rod is attracted towards the ebonite rod.

D.18.3 Elementary Charge The smallest quantity of electric charge.

TYPE OF QUANTITY Scalar.

WRITTEN REPRESENTATION e

SPECIFICATION Magnitude 1.602×10^{-19} C. Sign either positive or negative.

NOTES (i) The charge of an electron is $-e$ and that of a proton $+e$.

(ii) So far no elementary particle has been detected which has charge less than this amount although *theoretically* particles (*quarks*) of charge $\pm(1/3)e$ and $+(2/3)e$ are predicted.

18.2 FORCES BETWEEN TWO CHARGES

D. 18.4 Electric Force—Coulomb Force The force exerted by one charged body on another charged body at a distance.

TYPE OF QUANTITY Vector.

WRITTEN REPRESENTATION $\mathbf{F}$ or $\mathbf{F}_e$.

SPECIFICATION For two stationary charged bodies, force is specified by Coulomb's law (see Law 20). Measured in newton (N).

NOTES (i) This is the second important kind of force discussed in this book. The first was the gravitational force (D.4.7). Each of these forces arise from a different property of matter but have a somewhat similar mathematical expression (E. 4.6 and E. 18.1).

(ii) Among all the forces in nature, the electric force is the second strongest and perhaps the most important one. The attractive electric force between opposite charges holds all physical bodies together. An atom cannot exist without the strong attrac-

tive electric force between its electrons and protons. (see also D.4.3).

(iii) Apart from the difference in the magnitude of gravitational and electrical forces, see Example 18.1, electrical forces can be both attractive and repulsive due to the existence of two kinds of charged bodies.

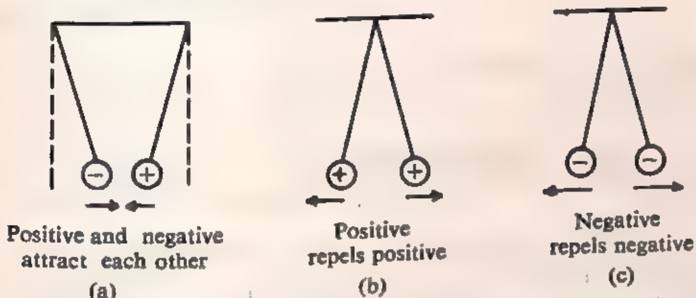


FIG. 18.2 Kind of electrical forces. (a) An attractive force exists between two objects if they carry opposite charges. (b), (c) The electrical force is repulsive if two objects carry similar charges Notice that when a force F acts on one charge, another force $-F$ acts on the other charge (Newton's third law)

D. 18.5 Coulomb The SI unit of electric charge named after the famous scientist Coulomb (1736-1806).

TYPE OF QUANTITY Derived SI unit.

WRITTEN REPRESENTATION C

SPECIFICATION The magnitude of charge present on each one of two equally charged bodies which exert an electric force of magnitude 9×10^9 N on each other, when placed one metre apart in vacuum.

Or

The charge transported in one second by an electric current of one ampere (D.18.16).

MATHEMATICAL EXPRESSION From the second specification

$$1\ \text{C} = 1\ \text{coulomb} = 1\ \text{ampere} \times 1\ \text{second} = \text{As}$$

LIMITATION The coulomb is a measure of only the *magnitude* of charge. The type of charge has to be specified separately.

LAW 20: COULOMB'S LAW

The force exerted by a charge of magnitude q_1, on a charge of magnitude q_2 at a distance r, is

(a) directly proportional to the product of the magnitudes of the two charges; and

(b) inversely proportional to the square of the distance separating the two charges, and acts along the line joining the positions of the two charges.

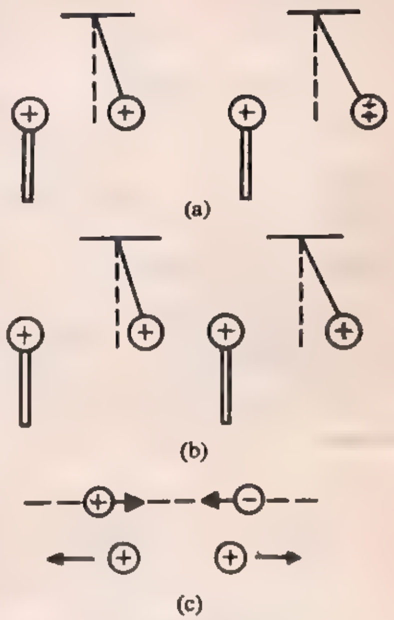
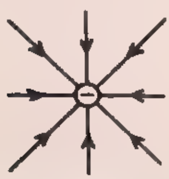


FIG. 18.3 Coulomb's law gives the force on one charged object due to another object. (a) The electrical force between two charged bodies can be increased by increasing the charge on either object. (b) The force can also be increased by decreasing the distance between them. (c) The force acts along the line joining the centre of the two charges.

(a) A positive point charge



(b) A negative point charge

FIG. 18.4 The electric field pattern due to point charge.

MATHEMATICAL EXPRESSION From the above statement

$$F \propto q_1 q_2$$
$$\propto \frac{1}{r^2}$$

or,

$$F = K \frac{q_1 q_2}{r^2} \qquad (E.18.1)$$

where K is the constant of proportionality and has the value 9×10^9 N m^2 C^{-2}.

D. 18.6 Electric Field—Coulomb Field The region around a charge within which it is capable of exerting a force on another electric charge.

NOTE The concept of the electric field is extremely important in physics. It helps us to understand how the electric force due to a charge can be experienced at a distance from the charge.

D. 18.7 Electric Line of Force An imaginary smooth curve in an electric field, along which a free positive charge would move if allowed to do so. See Fig. 18.4.

D. 18.8 Electric Field Strength (*Intensity*) A measure of the electric field around a charge q_1.

TYPE OF QUANTITY Vector

WRITTEN REPRESENTATION **E**

SPECIFICATION The force experienced by a unit positive charge at a given point in an electric field due to a charge q_1. Measured in newton per coulomb (NC^{-1}) or volt-metre (Vm). See Fig. 18.5 for direction.

FIG. 18.5 The direction of electric field strength E for $+q$ is away from $+q$ and for $-q$ is towards $-q$, along the line joining the unit positive charge and the centre of charge q.

MATHEMATICAL EXPRESSION From the specification and E.18.1,

$$E = K \frac{q_1}{r^2} \qquad (E.18.2)$$

NOTES (i) As the distance from the charge q increases the magnitude of E becomes smaller and smaller.

(ii) If a charge q_2 is placed at a distance r from the charge q_1, and the electric field strength at q_2 is E, the force acting on q_2 is given in magnitude by

$$F = q_2 E \qquad (E.18.3)$$

This expression is easily obtained by comparing E.18.1 and E.18.2.

(iii) The old name electric intensity is no longer used.

D.18.9 Uniform Electric Field An electric field in which the value of E is the same at all points in the electric field.

PICTORIAL REPRESENTATION By parallel lines.

EXAMPLE The electric field between two oppositely charged plates.

D.18.10 Work Done by a Uniform Electric Field of Intensity E on a Charge q The product of the Coulomb force, exerted on a charge q in an electric field of uniform intensity E, and the distance moved by the charge q.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION W

SPECIFICATION Magnitude measured in joule (J).

MATHEMATICAL EXPRESSION From the above definition

$$W = F_e\, s \qquad (E.18.4)$$

From E.18.3, $F_e = q\,E$ at a point r in the field. In the present case E is same at all points, and hence constant over the distance moved. Therefore,

$$W = q\,E\,s \qquad (E.18.5)$$

D.18.11 Electrostatic Potential Energy of a Charge q_2 due to a Charge q_1 at a Distance r from q_1 The quantity of work done by or against the electric field of a charge q_1 in displacing another charge q_2 from infinity to a distance r from q_1.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION ϕ or ϕ_e

SPECIFICATION Magnitude measured in joule (J).

MATHEMATICAL EXPRESSION

$$\phi = -K\,\frac{q_1 q_2}{r} \qquad (E.18.6)$$

D.18.12 Electric Potential (*or, simply, Potential*) A measure of the work done by a unit positive charge in an electric field. This is another measure of the electric field strength.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION V

SPECIFICATION The electric potential due to a charge q_1 at a distance r is the quantity of work done by or against the electric field of charge q_1 in displacing a unit positive charge from infinity to a distance r from q_1. Measured in joule J C^{-1}.

MATHEMATICAL EXPRESSION

$$V = -K\,\frac{q}{r} \qquad (E.18.7)$$

NOTES (i) The potential can be positive or negative.

(ii) The potential in electricity plays the same role as the temperature plays in the study of heat energy.

(iii) The earth is assumed to be at zero potential.

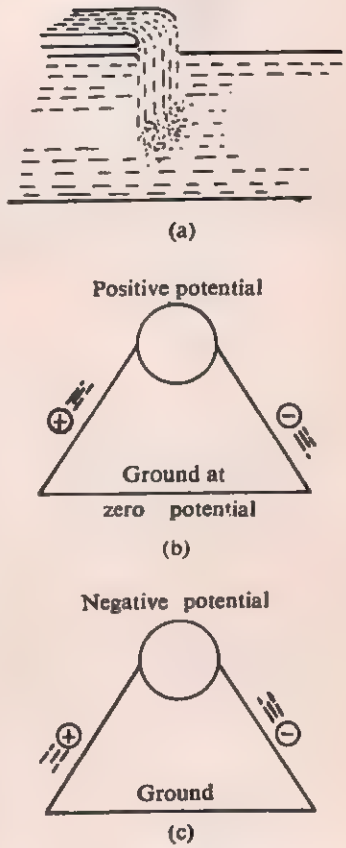


FIG. 18.6 The positive charge flows from a region of higher potential to a region of lower potential, similar to the flow of water from a higher potential energy region to a lower potential energy region, or the flow of heat energy from a region of higher temperature to a region of lower temperature.

D.18.13 Electric Potential Difference between Two Points *(or, simply, Potential Difference, or Voltage)* A measure of work done in carrying a unit positive charge between two points in an electric field.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION V_{AB}, V, PD

SPECIFICATION The amount of work done, by or against the electric field, in moving a unit positive charge from point A in the field to point B. Measured in volt (V). See D.18.14.

MATHEMATICAL EXPRESSION If W_{AB} is the work done in moving a charge q from point A to point B,

$$V_{AB} = V_A - V_B = \frac{W_{AB}}{q} \qquad (E.18.8)$$

NOTES (i) The potential difference between two points in an electric field is usually far more important than the other quantities mentioned above.

(ii) The work done in displacing a charge q_1 from point A to point B in a uniform electric field of intensity E is, from E.18.5,

$$W_{AB} = q\,E\,(r_A - r_B) \qquad (E.18.9)$$

RELATION BETWEEN POTENTIAL DIFFERENCE AND ELECTRIC FIELD STRENGTH Substituting the expression E.18.8 in E.18.9, we get

$$V_{AB} = Ed \qquad (E.18.10)$$

where d is the distance between points A and B.

LIMITATION This relation is true in this form only for a uniform electric field.

D.18.14 Volt The SI unit of electric potential difference.

TYPE OF QUANTITY Derived SI unit

WRITTEN REPRESENTATION V

SPECIFICATION The potential difference between two points in an electric field when one joule of work is done in moving a unit positive charge from one point to the other.

MATHEMATICAL EXPRESSION

$$1\ \text{volt} = \frac{1\ \text{joule}}{1\ \text{coulomb}} = \text{J C}^{-1} \qquad (E.18.11)$$

18.3 THE ELECTRIC CURRENT

The preceding section was devoted to the effects and properties of stationary charged bodies. When charges move, their behaviour is very different, and so are their effects. Electric currents are produced when a large number of charges move in an orderly fashion. Electric currents play an extremely important role in our lives today.

D.18.15 Electric Current The flow of electric charge through or across a particular region in space or in matter

TYPES OF ELECTRIC CURRENT There are two basic types of electric current. *Direct current* (DC) is observed when electric charge flows in one direction only throughout the time for which the current is produced. *Alternating current* (AC) is observed when the direction of the flow of charge reverses itself over a definite time period. That is, for one half of the time, the charge flows in one direction, and for the other half, it flows in exactly the opposite direction.

D.18.16 Electric Current Strength (*or, simply, Current*) The rate of flow of electric charge through a region or material.

TYPE OF QUANTITY Vector; but treated as scalar.

WRITTEN REPRESENTATION I

SPECIFICATION Magnitude measured in ampere (A) (D.18.17). See Fig. 18.8 for direction.

MATHEMATICAL EXPRESSION From the above definition,

$$I = \frac{q}{t} \qquad (E.18.12)$$

where q is the quantity of charge passing through a particular region in time t

NOTES (i) Any flow of electric charge constitutes a current. Thus, we can speak of a current when an electron moves around the nucleus of an atom, or when electrons travel through a metallic wire, or when they travel in a stream in a television tube.

(ii) Electric current in a metallic wire is due to the flow of negative charge (electrons). Earlier, current in wires was believed to be due to the flow of positive charge.

(iii) The current strength may be either constant or varying. Currents with constant magnitude are called *steady currents*. Those which have changing magnitude are called *varying currents*.

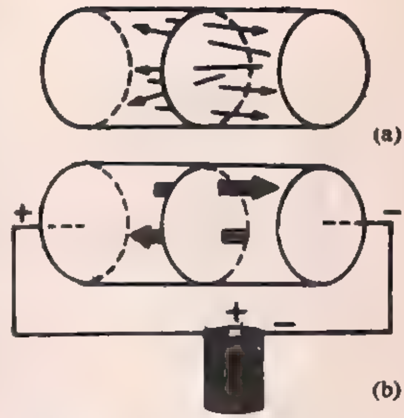


Fig. 18.7 (a) In a metallic wire at any instant, as many electrons move right through a particular cross sectional area as move to the left. (b) When a battery is connected to a conductor, electrons move in orderly manner towards the positive terminal of the battery.

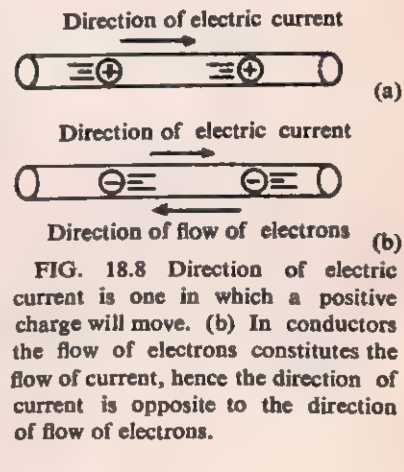


FIG. 18.8 Direction of electric current is one in which a positive charge will move. (b) In conductors the flow of electrons constitutes the flow of current, hence the direction of current is opposite to the direction of flow of electrons.

TABLE 18.1 Some sources of electric current.

Source	*Process*
Dry cells, accumulators	Convert chemical energy into electrical energy.
Thermal power plants	Thermal energy from burning of coal is converted into electrical energy.
Nuclear power plants	Convert mass energy during fission into electrical energy.
Hydroelectric generators	Convert kinetic energy and potential energy of water in dams to electrical energy.
Solar cells	Convert light energy into electrical energy.

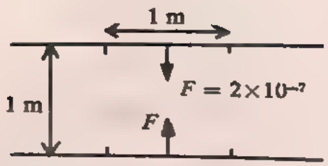


FIG. 18.9 Definition of ampere—base SI unit

D.18.17 Ampere A base SI unit of electric current.

WRITTEN REPRESENTATION A

SPECIFICATION The magnitude of the constant current, which if maintained in two parallel, rectilinear conductors of infinite length and of negligible circular cross-section, and placed at a distance of one metre from one another in vacuum, will produce between the conductors a force equal to 2×10^{-7} newton per metre of length.

D.18.18 Cell An electrical component which converts chemical energy into electrical energy.

NOTES (i) Inside the cell the direction of the current is from the negative terminal to the positive terminal.

(ii) A cell also has a resistance. For a new cell it is low. As the cell is used, it increases. When the cell is completely discharged its internal resistance is very high and no current can pass through it.

(iii) When a current flows through a circuit, an electron leaves the negative terminal and reaches the positive terminal after doing work. The potential energy of the electron at the negative terminal *exceeds* that of the electron at the positive terminal by an amount equal to the PD between the terminals of the cell.

D.18.19 EMF or e.m.f A measure of the potential difference between two terminals of a cell.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION ξ, E

SPECIFICATION The potential difference between two terminals of a cell when *no* current is drawn from it. Measured in volts (V).

NOTES (i) The word EMF stands for electromotive force. This word is a misnomer because sources of EMF (sources of electric current) supply electrical energy and have nothing to do with force. EMF is now used only in the abbreviated form and not in the misleading 'electromotive force' form.

(ii) When a current is drawn from a cell the potential difference between its two terminals is always *less* than the EMF (See D.18.20).

(iii) EMF is usually measured by placing a voltmeter in parallel with the cell terminals. Since the resistance of the voltmeter is very high it practically does not draw any current. Therefore, the voltmeter reading is taken as the EMF of the cell.

D.18.20 Lost EMF A measure of the change in EMF when a cell is in operation.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION No fixed symbol.

SPECIFICATION The difference between the EMF of a cell and the potential difference between the two terminals of a cell when current is drawn from it.

MATHEMATICAL EXPRESSION

$$\text{Lost EMF} = \text{EMF} - \text{PD between cell terminals when it is used}$$

NOTES (i) The lost EMF is always positive.

(ii) EMF decreases because part of the EMF is used up in driving current through the cell.

D.18.21 Electrical Conduction The property of some materials, usually in the shape of a wire or a rod or a plate, by virtue of which an electric current can pass through them.

TYPES OF CONDUCTORS

(*a*) *Good conductors* Those materials which can conduct an electric current easily and efficiently (without much loss of energy). For these materials the resistance (D.18.24) is very small.

EXAMPLES All metals.

(*b*) *Bad conductors* (*or, Insulators*) Those materials which cannot conduct a current easily or efficiently. The resistance of these materials under normal conditions is very high.

EXAMPLES Wood, glass, plastics, etc.

D.18.22 Ohmic Conductor (Ohmic Device) An electrical conductor for which Ohm's law is valid (graph between V and I is a straight line).

EXAMPLES All metals and alloys.

D.18.23 Non Ohmic Conductor (Non Ohmic Device) An electrical conductor which allows flow of current but Ohm's law is not valid (graph between V and I is not a straight line).

EXAMPLES Vacuum tubes (diode D.20.14, triode D.20.19), semiconductors (transistors).

D.18.24 Electrical Resistance (*or, simply, Resistance*) A measure of the property of all materials due to which they oppose the flow of electric current through them.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION Usually R

SPECIFICATION Magnitude measured in ohm (Ω).

NOTES (i) All materials (whether good conductors, bad conductors, or non-conductors) posses resistance.

(ii) There is no material, at room temperature, for which resistance is zero. However, at very low temperatures some sub-

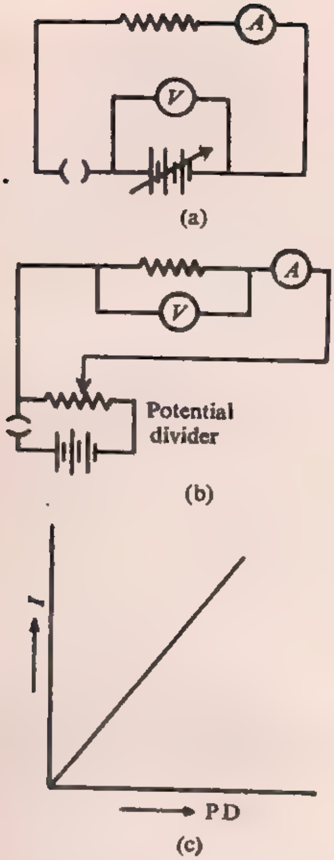


Fig. 18.10 Verification of Ohm's law. Set up the circuit shown. The applied potential difference can be changed either by using different number of cells each time or by using a potential divider arrangement. Change the PD and note the current. A graph between PD and I is a straight line, with slope being equal to the resistance.

stances can have almost zero resistance. Such materials are known as *superconductors.*

(iii) Resistance can also be defined through Ohm's law (Law 21), which provides a relation between current, potential difference and resistance.

(iv) The current in a metallic wire is due to the flow of electrons. These electrons while moving in the conductor collide with the atoms of the lattice and thus their movement is impeded. This obstruction to the movement of the electrons due to collision with atoms is the cause of resistance in the conductor.

LAW 21: OHM'S LAW

The potential difference across the ends of an electrical conductor is directly proportional in magnitude to the current flowing through it, provided the temperature of the conductor and all other physical conditions remain unchanged.

MATHEMATICAL EXPRESSION From the above definition

$$V \propto I,$$

or

$$V = IR \qquad (E.18.13)$$

NOTES (i) Ohms's law is valid when an electric current flows through a material body. When electric charge passes through air or vacuum [e.g. in a flash of lightning, or in an electronic tube like the triode] the current does not obey E.18.13.

(ii) Ohm's law is applicable to all electrical circuits involving ordinary conductors and resistors.

(iii) Ohm's law (E.18.13) is true only when the conduction of current does not cause heating (i.e. when the temperature of the conductor remains close to room temperature).

D.18.25 Ohm A unit of resistance.

TYPE OF QUANTITY Derived SI unit

WRITTEN REPRESENTATION Ω

SPECIFICATION The resistance offered by a conductor when a current of one ampere flows across a potential difference of one volt applied between the two ends of the conductor (see Ohm's law.)

MATHEMATICAL EXPRESSION

$$1 \text{ ohm} = \frac{1 \text{ volt}}{1 \text{ ampere}} = \text{V A}^{-1} \qquad (E.18.14)$$

D.18.26 Resistance of a wire The resistance, R, of a wire is experimentally found to depend on the following factors:

(i) $R \propto l$ (length of the wire)

(ii) $R \propto \frac{1}{A}$ (A = area of cross-section of wire)

or, $$R = \rho \frac{l}{A} \tag{E.18.15}$$

ρ is the constant of proportionality (D.18.27).

D.18.27 Specific Resistance—Resistivity A characteristic electrical property of a substance.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION No fixed symbol (ρ in this book).

SPECIFICATION The resistance between the ends of a conducting wire of length 1 m and uniform cross-sectional area of 1 m². Measured in ohm-metre (Ωm).

D.18.28 Electrical Resistor A device consisting of a conductor or nonconductor, usually in the shape of a wire, which offers resistance to a current.

PICTORIAL REPRESENTATION See Fig. 18.11.

FIXED AND VARIABLE RESISTANCE For practical reasons, resistors are designed to provide either a fixed magnitude of resistance or a variable magnitude of resistance. Fixed resistance is shown in Fig. 18.11(a), while that with variable resistance is shown in Fig. 18.11(b).

TABLE 18.2 Specific resistance (ρ) of some materials

Material	$\rho(\Omega m^{-1})$
Alcohol	3×10^3
Aluminium	2.82×10^{-8}
Bakelite	5×10^8
Copper	1.75×10^{-8}
Glass	2×10^{11}
Gold	2.44×10^{-8}
Iron	7×10^{-8}
Nichrome	100×10^{-8}
Nylon	4×10^{12}
Silver	1.59×10^{-8}
Water	$\approx10^5$
Wood	5×10^{14}

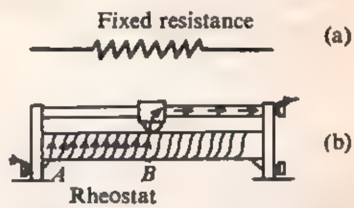


FIG. 18.11 (a) Pictorial representation of a fixed resistance. (b) Rheostat is an appliance to give variable resistance. It has a coil of resistance wire with a sliding contact. The resistance in the circuit is the resistance of the wire between points A and B.

18.4 ELECTRICAL CIRCUITS

Electrical circuits are basically designed for converting electrical energy into other useful forms of energy.

D.18.29 Electrical Circuit (*or, simply, Circuit*). An arrangement of electrical conductors, resistors, etc. such that a current can flow through all its parts.

CIRCUIT ELEMENTS

An electrical circuit is essentially made of the following parts.

1. *Source of EMF—Source of potential difference—Source of electrical energy* It drives a current through the circuit.

EXAMPLES Cell, AC from mains, generator.

2. *Resistance* An electrical circuit must contain some resistors. If no resistors are present, a very large current will flow through the source and may damage it.

NOTE In these circuit elements most of the electrical energy is converted into heat energy.

3. *Connecting wires* These are made of good conductors such as copper or aluminium.

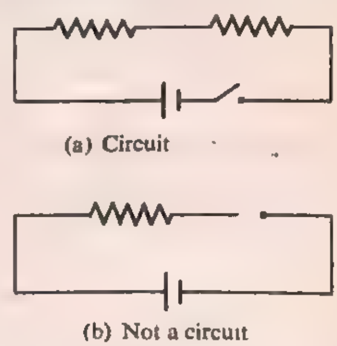


FIG. 18.12 An electrical circuit is an arrangement of electrical components such that current passes through all of them simultaneously.

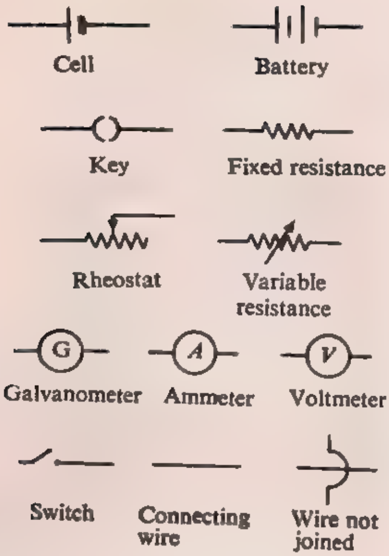


FIG. 18.13 Symbols used for electrical components.

4. *Measuring instruments* The instruments such as ammeter (which measures current in the circuit, D.19.24), voltmeter (which measures potential difference between two points, D.19.25), galvanometer (which detects presence of current in the circuit D.19.23) etc.

D.18.30 Equivalent Resistance The resistance of a single resistor, which can be inserted in a circuit to replace two or more resistors without disturbing the current flowing through the circuit. Two cases of combining resistances are as follows.

Case I: Resistors in series When resistors are placed in such a way that current flows first through one and then through the second and so on, the resistors are said to be in series. (The same current flows through all the resistors but the potential difference across each resistor is different.)

According to Ohm's law (see Fig. 18.14)

$$V_1 = IR_1,\ V_2 = IR_2,\ V_3 = IR_3 \qquad (E.18.16)$$

From Fig. 18.14(a)

$$V = V_1 + V_2 + V_3 = I(R_1 + R_2 + R_3) \qquad (E.18.17)$$

From Fig. 18.14(b)

$$V = IR \qquad (E.18.18)$$

Comparing E.18.17 and E.18.18,

$$R = R_1 + R_2 + R_3$$

For many resistors in series, the equivalent resistance is

$$R = R_1 + R_2 + R_3 + \dots \qquad (E.18.19)$$

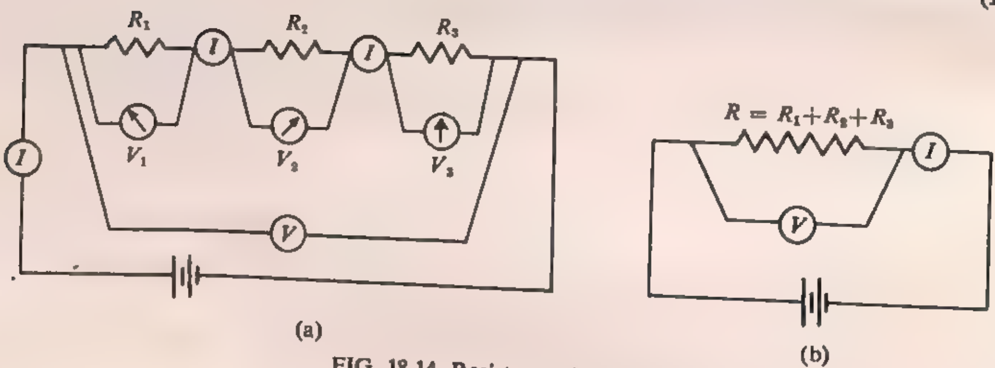


FIG. 18.14 Resistances in series.

NOTE The equivalent resistance is more than the individual resistances.

Case II: Resistors in parallel Resistors are in parallel arrangement in a circuit when current enters all of them simultaneously. (Different currents flow through each but all of them are at the same potential difference.)

According to Ohm's law (Fig. 18.15),

$$I_1 = \frac{V}{R_1},\quad I_2 = \frac{V}{R_2},\quad I_3 = \frac{V}{R_3}$$

From Fig. 18.15(a)

$$I = I_1 + I_2 + I_3 = V\left(\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}\right) \qquad (E.18.20)$$

From Fig. 18.15(b)

$$I = \frac{V}{R} \qquad (E.18.21)$$

Comparing E.18.20 and E.18.21,

$$\frac{1}{R} = \frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}$$

For more than three resistances in parallel, the equivalent resistance is

$$\frac{1}{R} = \frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\cdots \qquad (E.18.22)$$

NOTE The equivalent resistance is less than the smallest individual resistance.

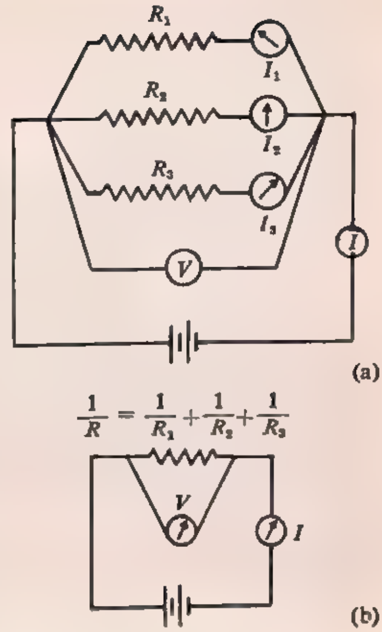


FIG. 18.15 Resistances in parallel.

SOLVED EXAMPLES

(*Note*: Wherever necessary take $K = 9\times10^9$ N m^2 C^{-2}.)

EXAMPLE 18.1 The first element of the periodic table, hydrogen, has a proton and an electron separated by an average distance of 5.3×10^{-11}m. The proton has a charge of $+1.6\times10^{-19}$ C and the electron charge is -1.6×10^{-19} C. Calculate the electrical force between the electron and proton. Is the force attractive or repulsive?

Solution $q_1 = +1.6\times10^{-19}$ C, $q_2 = -1.6\times10^{-19}$ C and $r = 5.3\times10^{-11}$ C. From Coulomb's law,

$$F = K\frac{q_1q_2}{r^2}$$

$$= 9\times10^9 \text{ Nm}^2\text{ C}^{-2} \times \frac{-1.6\times10^{-19}\text{ C}\times1.6\times10^{-19}\text{ C}}{(5.3\times10^{-11}\text{ m})^2}$$

$$= -8.2\times10^{-8}\text{ N.}$$

Since the sign is negative the force is attractive.

Answer The magnitude of the force between the electron and proton in a hydrogen atom is 8.2×10^{-8} N. The force is attractive.

NOTE The gravitational force between the electron and proton in a hydrogen atom is 3.61×10^{-49} N (see Example 4.17).

EXAMPLE 18.2 The repulsive force between two electric charges 0.01 m away from each other is 4 N. The two charges are brought closer until the force of repulsion becomes 16 N. What is the new separation?

Solution Let the two charges be q_1 and q_2. From Coulomb's law,

$$F = K\frac{q_1q_2}{r^2}, \text{ or } Kq_1q_2 = Fr^2.$$

First case $F = 4$ N and $r = 0.01$ m.

$$Kq_1q_2 = 4\,\text{N} \times (0.01\ \text{m})^2 = 4 \times 10^{-4}\ \text{Nm}^2$$

Second case $F = 16$ N and r is to be determined.

$$Kq_1q_2 = 16\,\text{N} \times r^2.$$

Substitute the value of Kq_1q_2 to obtain

$$16\,\text{N} \times r^2 = 4 \times 10^{-4}\ \text{Nm}^2,$$

or $$r^2 = 10^{-4}\ \text{m}^2/4,$$

or $$r = 0.005\ \text{m}.$$

Alternative method If F_1, r_1 are the force and separation in the first case and F_2, r_2 are the force and separation in the second case, then a straightforward application of Coulomb's law gives $F_2 r_1^2 = F_2 r_2^2$. Substitute the various values to obtain r^2.

Answer The new separation between the two charges is 0.005 m.

EXAMPLE 18.3 Two charges 5×10^{-10} C and 15×10^{-11} C are placed one metre apart. Determine the electric intensity at a point midway between the two charges.

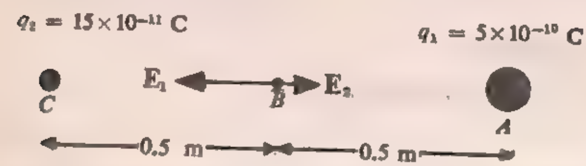


FIG. 18.16 Example 18.3.

Solution $q_1 = 5 \times 10^{-10}$ C, and $q_2 = 15 \times 10^{-11}$ C. The magnitude of electrical intensity due to a charge q at a distance r is $E = Kq/r^2$.

$\mathbf{E}_1$ = electrical intensity due to q_1 at point B

$$= \frac{9 \times 10^9\ \text{Nm}^2\,\text{C}^{-2} \times 5 \times 10^{-10}\ \text{C}}{0.5\ \text{m}}$$

= 9 NC^{-1} directed towards the point C

$\mathbf{E}_2$ = electrical intensity due to q_2 at point B

$$= \frac{9 \times 10^9\ \text{Nm}^2\,\text{C}^{-2} \times 15 \times 10^{-11}\ \text{m}}{0.5\ \text{m}}$$

= 2.7 NC^{-1} directed towards the point A.

The electrical intensities $\mathbf{E}_1$ and $\mathbf{E}_2$ are opposite to each other. Hence from the law of addition of vectors (see Chapter 2, Vol. 1),

$\mathbf{E}$ = resultant of $\mathbf{E}_1$ and $\mathbf{E}_2$

= $\mathbf{E}_1 - \mathbf{E}_2$ = 9 NC^{-1} directed toward C − 2.7 NC^{-1} directed towards A

= 6.3 NC^{-1} directed towards C.

Answer The electric intensity at the given point is 6.3 NC^{-1} directed towards the charge 15×10^{-11} C, along the line joining the two charges.

EXAMPLE 18.4 An electron is placed in an electric field of uniform intensity $10^4\ \text{NC}^{-1}$ (such a field exists in TV tubes, X-ray tubes, tube diodes, etc). Calculate (i) the force on the electron, (ii) the work done on the electron in moving through a distance of 5 mm, and (iii) the acceleration of the electron. Mass of the electron = 9.1×10^{-31} kg.

Solution $E = 10^4\ \text{NC}^{-1}$, $m = 9.1 \times 10^{-31}$ kg, $s = 5$ mm $= 0.005$ m, $e = -1.6 \times 10^{-19}$ C.

(i) Force = charge × electron intensity = Eq

$$= -10^4\ \text{NC}^{-1} \times 1.6 \times 10^{-19}\ \text{C}$$
$$= -1.6 \times 10^{-15}\ \text{N}.$$

(i) Work done = force × distance moved

$$= Eqs = -10^4\ \text{NC}^{-1} \times 1.6 \times 10^{-19}\ \text{C} \times 0.005\ \text{m}$$
$$= -8 \times 10^{-18}\ \text{J}.$$

(iii) From Newton's second law of motion,

$$a = \frac{F}{m} = \frac{-1.6 \times 10^{-15}\ \text{N}}{9.1 \times 10^{-31}\ \text{kg}}$$
$$= -1.8 \times 10^{15}\ \text{ms}^{-2}.$$

Answer The force on the electron is -1.6×10^{-15} N, work done by the field is -8×10^{-18} J and acceleration of the electron is $-1.8 \times 10^{15}\ \text{ms}^{-2}$.

EXAMPLE 18.5 Calculate the electrostatic potential energy of a system in vacuum having two charges −0.30C and 6.0C. The distance between the two charges is 120 cm.

Solution $q_1 = 0.3$ C, $q_2 = 6$C and $r = 120$ cm $= 1.2$ m.

$$= -\frac{Kq_1q_2}{r}$$

$$= -\frac{9\times10^9\ \text{Nm}^2\text{C}^{-2}\times(-0.3\ \text{C})\times6\ \text{C}}{1.2\ \text{m}}$$

$$= 1.35\times10^{10}\ \text{J}$$

Answer The electrostatic energy of the system is 1.35×10^{10} J.

EXAMPLE 18.6 A charge of magnitude 10^{-10} C is moved from infinity to a given point in the presence of another charge. If the work done is 10^{-8} J, calculate the potential at the given point.

Solution $W = 10^{-8}$ J, and $q = 10^{-10}$ C.

$$\text{Magnitude of the potential} = \frac{W}{q}$$

$$= \frac{10^{-8}\ \text{J}}{10^{-10}\ \text{C}} = 100\ \text{JC}^{-1}.$$

Answer The magnitude of the potential at the given point due to the other charge is 100 J C^{-1}.

EXAMPLE 18.7 The potential at a point A is 300 J C^{-1} and at point B is 500 J C^{-1}. Calculate the potential difference in volts between points B and A. What will be the work done by a charge of 10^{-3} C in moving from point B to point A?

Solution $V_A = 300$ J C^{-1}, $V_B = 500$ J C^{-1}, and $q = 10^{-3}$ C.

V_{BA} = potential difference between point B and point $A = V_B - V_A$

$$= 500\ \text{J C}^{-1} - 300\ \text{J C}^{-1}$$

$$= 200\ \text{V}.$$

Further,

$$V_{BA} = \frac{W_{BA}}{\text{charge}},\ \text{or}$$

W_{BA} = work done in moving the charge from B to A

$$= V_{BA}\times q = 200\ \text{V}\times10^{-3}\ \text{C} = 0.2\ \text{J}.$$

Answer The potential difference between point B and point A is 200 V and the work done in moving the given charge from B to A is 0.2 J.

NOTE If the charge is moved from point A to point B then the work done is -0.2 J.

EXAMPLE 18.8 Most of the functions of a biological cell like movement of fluid from inside the cell to outside and vice versa are governed by electrical phenomena. There exists, in general, a net negative charge on the inside of a cell while the fluid outside the cell contains positive charge. The charges are separated by a very thin cell membrane, which is about 1.5×10^{-8} m thick. If the potential difference across the cell membrane is 88 mV, determine the electric field strength across the membrane.

Solution $V_{AB} = 88$ mV $= 0.088$ V and $d = 1.5\mu$ cm $= 1.5\times10^{-8}$ m. The electric field strength = potential difference/separation between two points.

$$E = \frac{V_{AB}}{d} = \frac{0.088\ \text{V}}{1.5\times10^{-8}\ \text{m}}$$

$$= 5.9\times10^6\ \text{V m}^{-1}.$$

Answer The electric field strength between the two sides of the nerve membrane is 5.9×10^6 V m^{-1}.

EXAMPLE 18.9 In the human body, whenever any information is exchanged between two parts or an organ completes some action, there is always a flow of current. For instance when the heart is full of blood and is about to pump it into the artery, a current passes through the heart muscles. This current causes contraction of the heart, and consequently blood is pumped into the respective artery. It is observed that a current of the order of 10^{-11} A exists for about 0.16s. If we assume that this current is due to the flow of electrons, estimate how many electrons would have passed through the heart muscles?

Solution $I = 10^{-11}$ A, and $t = 0.16$s. We know that,

$$\text{Current} = \frac{\text{charge flowing}}{\text{time}},\ \text{or}$$

$$\text{Charge flowing} = It = 10^{-11}\ \text{A}\times0.16\text{s}$$

$$= 1.6\times10^{-12}\ \text{C}.$$

Number of electrons flowing

$$= \frac{\text{charge flowing}}{\text{charge of electron}}$$

$$= \frac{1.6 \times 10^{-12}\ \text{C}}{1.6 \times 10^{-19}\ \text{C}} = 10^7.$$

Answer The number of electrons passing through the heart muscles is 10^7.

Example 18.10 What should be the potential difference across a 20Ω resistance if the current through the resistor is 0.2 A?

Solution $R = 20\Omega$ and $I = 0.2$ A

$$V = IR = 20\Omega \times 0.2\ \text{A}$$
$$= 4\ \text{V}.$$

Answer The potential difference across the resistor should be 4 V.

Example 18.11 Calculate the equivalent resistances of the following combinations (Fig. 18.17a).

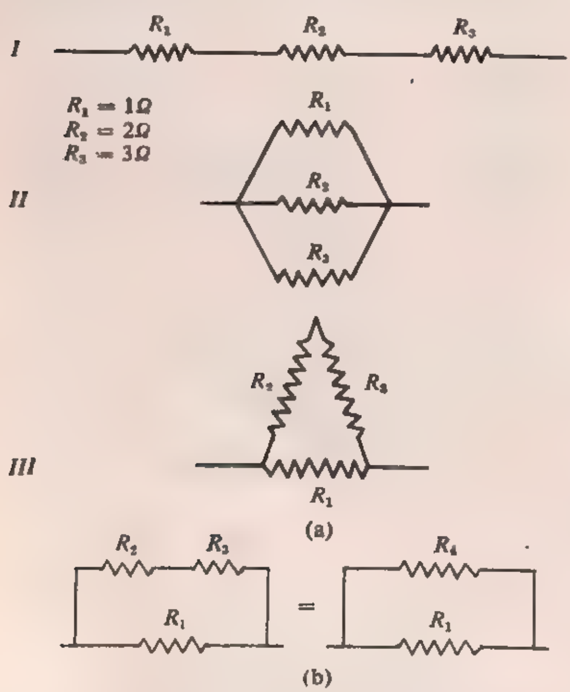


FIG. 18.17 Example 18.11.

Solution $R_1 = 1\Omega$, $R_2 = 2\Omega$, and $R_3 = 3\Omega$.
Case I: Three resistances are in series. For such a combination we know that the effective resistance R is

$$R = R_1 + R_2 + R_3$$
$$= 1\Omega + 2\Omega + 3\Omega = 6\Omega.$$

Case II: Here three resistances are in parallel because different current exists in each one of them. The effective resistance, R, for such a combination is,

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$
$$= \frac{1}{1\Omega} + \frac{1}{2\Omega} + \frac{1}{3\Omega} = \frac{6+3+2}{6\Omega}$$
$$R = (6/11)\ \Omega.$$

Case III: This combination can also be drawn as in Fig. 18.17b. We see that this is a mixed combination. Two resistances of 2Ω and 3Ω are in series. This series combination and the 1Ω resistance are in parallel. For the series combination,

$$R_4 = R_2 + R_3 = 2\Omega + 3\Omega = 5\Omega.$$

For the parallel combination

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_4} = \frac{1}{1\Omega} + \frac{1}{5\Omega} = \frac{6}{5}\ \Omega^{-1},$$

or $\quad R = \frac{5}{6}\ \Omega.$

Answer The effective resistances are (i) 6Ω, (ii) $(6/11)\Omega$, and (iii) $(5/6)\Omega$.

Example 18.12 Calculate the effective resistance, current in each resistance and potential difference across each resistance of the circuits shown in Fig. 18.18.

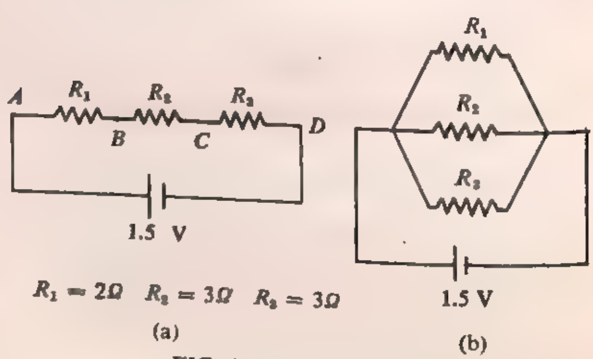


FIG. 18.18 Example 18.12.

Solution *Case I*: Since the three resistances are in series, the effective resistance R is,

$$R = R_1+R_2+R_3 = 2\Omega+3\Omega+4\Omega$$
$$= 9\Omega.$$

The potential difference between the points A and D is $V_{AD} = 1.5$ V. Let I be the current in the circuit. Then from Ohm's law,

$$I = \frac{V_{AD}}{R} = \frac{1.5 \text{ V}}{9\Omega} = \frac{1}{6} \text{ A}.$$

Now apply Ohm's law to the individual resistances

$$V_{AB} = R_1 I = 2\Omega\times\frac{1}{6} \text{ A} = \frac{1}{3} \text{ V}$$

$$V_{BC} = R_2 I = 3\Omega\times\frac{1}{6} \text{ A} = \frac{1}{2} \text{ V}$$

$$V_{CD} = R_3 I = 4\Omega\times\frac{1}{6} \text{ A} = \frac{2}{3} \text{ V}.$$

Case II: Here the three resistances are in parallel. The effective resistance R is,

$$\frac{1}{R} = \frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3} = \frac{1}{2\Omega}+\frac{1}{3\Omega}+\frac{1}{4\Omega}$$

or, $\quad R = \frac{12}{13}\,\Omega.$

Let I_1, I_2 and I_3 be the current in the resistances, R_1, R_2 and R_3 respectively. Apply Ohm's law to the individual resistances.

$$I_1 = \frac{V_{AD}}{R_1} = \frac{1.5 \text{ V}}{2\Omega} = 0.75 \text{ A}$$

$$I_2 = \frac{V_{AD}}{R_2} = \frac{1.5 \text{ V}}{3\Omega} = 0.5 \text{ A}$$

$$I_3 = \frac{V_{AD}}{R_3} = \frac{1.5 \text{ V}}{4\Omega} = 0.38 \text{ A}.$$

Answer For first combination: effective resistance is 9Ω: current in each resistance is (1/6) A; and the potential difference across 2Ω, 3Ω and 4Ω resistances is (1/3) V, (1/2) V, and (2/3) V, respectively.

For second combination: effective resistance is $(12/13)\Omega$; potential difference across each resistance is 1.5 V; and current in 2Ω, 3Ω and 4Ω resistances is 0.75 A, 0.5 A and 0.38 A respectively.

NOTE Check that in case I, $V_{AD} = V_{AB}+V_{BC}+V_{CD}$ and in case II, $I = I_1+I_2+I_3 = V_{AD}/R$.

EXAMPLE 18.13 Two positive charges of magnitude 2 C and 3 C are placed 0.1 m apart. Find the electric potential at a distance of 0.10 m on the right bisector from the line joining the two charges. See Fig. 18.19.

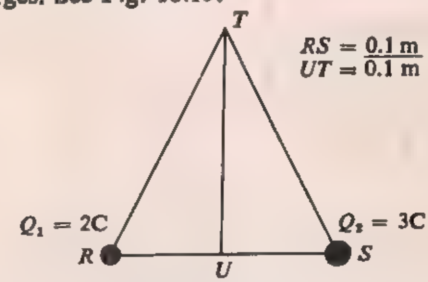


FIG. 18.19 Example 18.13.

Solution $RU=(1/2)RS=0.05$ m, $RT^2 = RU^2 + UT^2 = 0.01 \text{ m}^2+0.0025 \text{ m}^2$. Or $RT= \sqrt{125} \times10^{-2}$ m. The potential V due to a charge Q at a distance r is

$$V = K\frac{Q}{r}$$

V_1 at T due to the charge at R is

$$\frac{9\times10^9 \text{ Nm}^2\text{ C}^{-2}\times2 \text{ C}}{\sqrt{125}\times10^{-2}\text{ m}}$$
$$= \frac{18\times10^{11}}{\sqrt{125}} \text{ J C}^{-1}.$$

V_2 at T due to charge at S is

$$\frac{9\times10^9 \text{ Nm}^2\text{ C}^{-2}\times3 \text{ C}}{\sqrt{125}\times10^{-2}\text{ m}}$$
$$= \frac{27\times10^{11}}{\sqrt{125}} \text{ J C}^{-1}.$$

Since potential is a scalar quantity, total potential at T is simply the algebraic sum of V_1 and V_2,

$$V = V_1+V_2 = \frac{18\times10^{11}}{\sqrt{125}} \text{ J C}^{-1}+\frac{27\times10^{11}}{\sqrt{125}} \text{ J C}^{-1}$$
$$= \frac{45\times10^{11}}{\sqrt{125}} \text{ J C}^{-1}.$$

Answer The potential due to the two charges at the given point is $\frac{45\times10^{11}}{\sqrt{125}}$ J C^{-1}.

EXAMPLE 18.14 In the circuit diagram given in Fig. 18.20 find (i) the total resistance of the circuit, (ii) the total current flowing in the ammeter, and (iii) the readings of voltmeters V1 and V2.

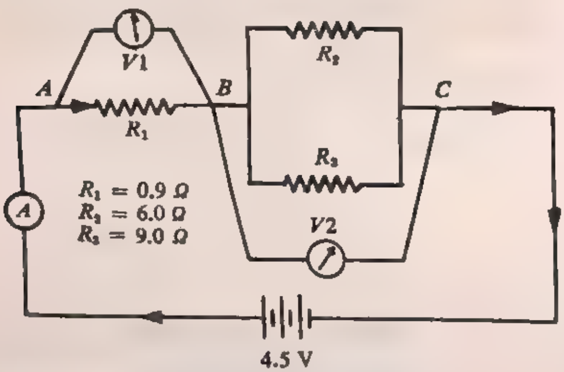


FIG. 18.20 Example 18.14.

Solution $R_1 = 0.9\Omega$, $R_2 = 6.0\Omega$, $R_3 = 9.0\Omega$ and EMF of the cell $= 4.5$ V.

(i) Let the equivalent resistance of R_2 and R_3, being in parallel, be R_4, then

$$\frac{1}{R_4} = \frac{1}{R_2} + \frac{1}{R_3}$$

or,

$$R_4 = \frac{R_2 R_3}{R_2 + R_3} = \frac{9\Omega \times 6\Omega}{15\Omega} = 3.6\Omega$$

The resistance R_1 is in series with R_4. Hence the total effective resistance is

$$R = 0.9\Omega + 3.6\Omega = 4.5\Omega.$$

(ii) Let I be the reading of the ammeter. It will be the same as the total current in the circuit. From Ohm's law

$$V = IR,$$

or

$$I = \frac{V}{R} = \frac{4.5\ \text{V}}{4.5\Omega} = 1\ \text{A}.$$

(iii) The reading in voltmeter V1 is the same as the potential difference across the points A and B in the circuit. Hence,

V_{AB} = Potential difference across points A and B

$$= R_1 I = 0.9\Omega \times 1\ \text{A} = 0.9\ \text{V}.$$

The reading in voltmeter V2 is the same as the potential difference across the points B and C. Hence,

$$V_{BC} = R_4 I = 3.6\Omega \times 1\ \text{A} = 3.6\ \text{V}.$$

Answer The total resistance and the current in the circuit are 4.5Ω and 1 A respectively. The readings of voltmeters V1 and V2 are 0.9 V and 3.6 V respectively.

PROBLEMS

18.1 In an NaCl molecule, an Na^+ ion with charge e is 2.4×10^{-10} m from a Cl^- ion with charge $-e$. What is the magnitude of the force between them?

18.2 A cell membrane 10^{-8} m thick has positive ions on one side and negative ions on the other. What is the force between two ions at this separation? The magnitude of charge on each ion is e.

18.3 When a person slides across an automobile seat and reaches for a door handle, electric charge can accumulate on the finger tips. If the attractive force between the fingers and the door handle is 2.5×10^{-3} N at a separation of 25 cm, determine the number of electrons accumulated on the fingertips. Assume that the number of charged particles is the same on the fingertips and the door handle.

NOTE A similar phenomenon occurs when one walks over a carpet to reach a door. In medical operation theatres, build up of such a static charge can be dangerous as anaesthetic chemicals can explode due to a spark.

18.4 A charge of magnitude 10^{-10} C is placed 10^{-9} m away from another charge of magnitude 5×10^{-3} C. Find the magnitude of the force between the two charges.

18.5 How far apart must two charges of 10^{-4} C and 9×10^{-6} C be placed if the force on each of them is to be 10 N?

18.6 Two equal charges 10^{-5} m apart exert a force of 3.6 N on each other. What is the magnitude of the charge?

18.7 Three 5 mC charges are placed in a straight line 50 cm apart. Find the force on the centre charge if (i) all the charges are negative, (ii) the two end charges are negative and the centre one positive, and (iii) only one end charge is positive.

18.8 How many electrons make up 1 C?

18.9 What is the total charge in coulombs of a body of mass 1 kg entirely made up of protons? (Mass of proton $= 1.6\times10^{-27}$ kg.)

18.10 The force between two charges at a certain distance of separation is 10^{-4} N. What will be the force if the distance between them is (i) doubled, and (ii) decreased to one-fourth?

18.11 Determine the force on charge q_3 of Fig. 18.21.

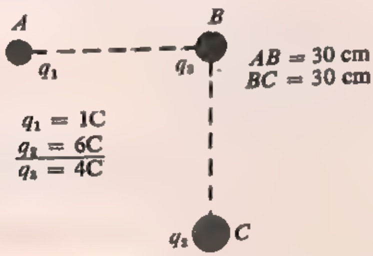


FIG. 18.21

18.12 The charge on the Uranium nucleus is $92e$. (a) What is the direction and magnitude of the electric field strength due to the nucleus at a distance of 10^{-5} m from the nucleus? (b) Determine the direction and magnitude of the force on an electron at this distance.

18.13 What is the force on an electron in a field of 10^5 NC^{-1}?

18.14 Calculate the electric field strength at a point 10^{-8} m from a charge of magnitude 10^{-8} C.

18.15 At what distance from a charge of magnitude 10^{-6} C, will the electric field strength be 2.25×10^6 NC^{-1}?

18.16 Two charges 6 μC and -3 μC are 60 cm apart. Find the electric field strength midway between them.

18.17 The electric field strength at a point A is 30 N due south. (i) What will it be if the sign of the charge is changed? (ii) What is the sign of the charge (which produces the field) if it is (a) to the south, (b) to the north of the point A?

18.18 Calculate the potential at a point 10 cm from a positive charge of magnitude 10^{-8} C.

18.19 If the potential at a point is 2 JC^{-1}, determine the amount of work done in bringing a charge of 2 μC from infinity to that point.

18.20 Find the potential at the point A in Fig. 18.22.

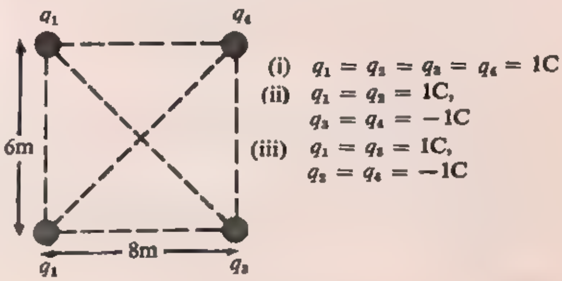


FIG. 18.22

18.21 How much work is done in moving (i) a charge of 2C from a point at 118 volts to a point at 128 volts? (ii) one coulomb charge against a potential difference of one volt.

18.22 Two charges q_1 and q_2 of 4 μC and -3 μC respectively are placed 0.6 m apart such that q_2 is to the left of q_1. Calculate the potential at a point (i) equidistant from both the charges, (ii) 0.3 m to the left of q_2, and (iii) 0.4 m to the right of q_1. All the three points lie on the line joining the two charges.

18.23 A carbon nucleus has a charge of $+6e$. At a distance of 10^{-10} m from a carbon nucleus find (a) the electric potential, (b) the potential energy of an electron.

18.24 Determine the potential difference between two points A and B if the work done in moving a unit positive charge from infinity to point A and B is 40 JC^{-1} and 60 JC^{-1} respectively.

18.25 Two parallel metal plates are connected to a 3.0 V battery. How far are the plates from each other if the field between the plates is 150 Vm^{-1}? What would be the force on an electron between the plates?

18.26 The potential difference between two metal plates placed parallel to each other in vacuum is 182 V. How fast will an electron be moving just before hitting the positive plate, if it is released at the negative plate? (Mass of electron $= 9.1\times10^{-31}$ kg.)

18.27 Through how large a potential difference must an electron fall if it is to acquire a speed of 4×10^6 ms^{-1} (use the relation $eV = \frac{1}{2} mv^2$)?

18.28 The electric field strength between two parallel plates is 500 Vm^{-1}. If the plates are 20 cm apart, what is the potential difference between the two plates?

18.29 In a two cell flashlight about 1.08 C of charge passes any given point of the flashlight circuit in 2.0 s. What is the current in the circuit?

18.30 An X-ray tube operates for one-fifth of a second at 100 mA. How much charge has passed through the tube?

18.31 10 C of charge passes through a particular section of a circuit in 10 s. What is the current through the circuit?

18.32 If the current in the circuit is 1.6 A how many electrons will pass through the circuit per second?

18.33 10^{18} electrons pass through a point in 10^{-5} s. Find the current in the circuit?

18.34 A certain atom-smashing machine operates at a potential difference of 1 MV and gives a current of 1 mA. How much charge does it provide in 1 hour?

18.35 Determine the potential difference across a resistor of 100Ω carrying a current of 3 A.

18.36 A certain toaster operates with a current of 6.0 A when the voltage across it is 220 V. What is the resistance of this toaster?

18.37 Calculate the current through a resistor of 4.0 Ω. Given that the potential difference across the resistor is 1.50 V.

18.38 What will be the resistance of a wire which carries a current of 0.6 A when the potential difference across it is 1.8 V?

18.39 A 12 volt car battery provides a current of 48 A when the car is being started. Calculate the resistance of the starter.

18.40 Determine the effective resistance between points A and B of the circuits shown in Fig. 18.23.

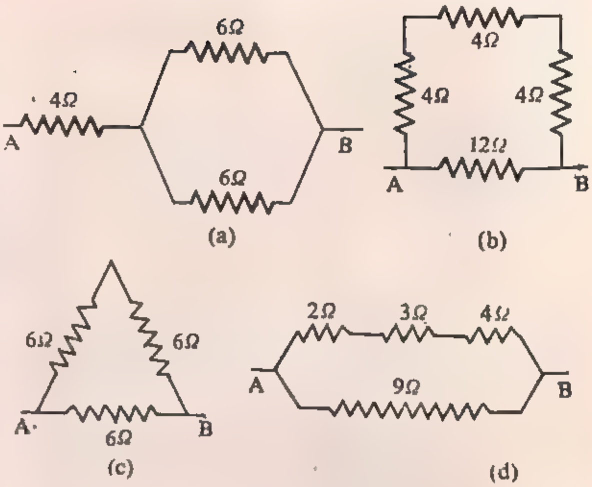


FIG. 18.23

18.41 Four 3.0Ω resistances are connected in series with a cell of EMF 1.50 V. What is the total resistance? Determine the current in the circuit and the potential difference across each resistance.

18.42 Two 4Ω resistances are connected in parallel with a cell of voltage 3 V. Calculate the current in each resistor.

18.43 Two bulbs of resistances 1000 Ω and 1200 Ω in series are connected to a supply of 220 V. How much current will flow through each of them?

18.44 At a point A, the electric field strength points (i) due north, (ii) due south and (iii) along the negative x-axis. In which direction will an electron move if it is placed at A?

18.45 Three resistances of 3Ω are connected to each other. Find the maximum and minimum resistances obtainable.

18.46 The physiological effects of an electric current on the human body depend on the magnitude of the current. The various effects are as follows.

Current through human body (A)	*Physiological effect*
0.001	Beginning of feeling.
0.005	Maximum harmless current.
0.007 to 0.015	Not possible to withdraw hand from the wire (paralysis).
0.050	Pain, fainting, exhaustion.
0.1 to 0.3	Ventricular fibrillation.
above 0.3	Ventricular paralysis and burns.

The dry human body resistance is about 10 000Ω (for wet skin it can decrease drastically). Calculate the corresponding potential difference which will send the above currents.

18.47 Find the resistance of a square biological cell membrane of side 1.00 μm and 7.50×10^{-9} m thick. The specific resistance of the material of the cell membrane is 1.33×10^7 Ω m^{-1}.

18.48 If the voltage across a cell membrane is 9.98 mV how much (i) current and (ii) electrons per second, would flow through the membrane. Take the relevant data from 18.47.

NOTE : The movement of this large charge is the cause of most of the activities of a biological cell.

18.49 In 18.1 and 18.4 find the electrostatic potential energy of the system.

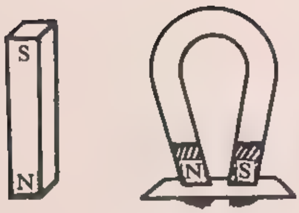
18.50 A system of two equal positive charges has potential energy -9×10^{7} J. If the separation between them is 25 cm, determine the magnitude of the charge.

18.51 By what fraction will the electrostatic potential energy of an electrical system change if (i) one of the charges is doubled, (ii) both the charges become one third of the original value, (iii) distance between the charges is reduced by half, and (iv) one of the charges is reduced by half and simultaneously distance between them is doubled?

18.52 Do Problem 18.51 for force between two charges.

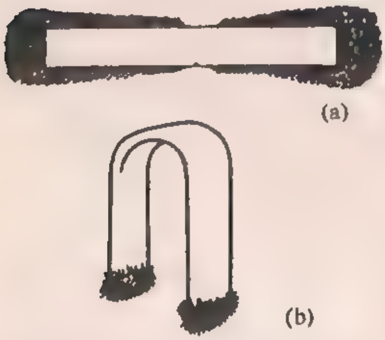
18.53 The potential energy of an electrical system is (i) negative, (ii) positive. What is the sign of each charge?

19 Magnetic Effects of Current



(a) (b)

FIG. 19.1 Two basic kinds of magnets, (a) bar magnet and (b) horse shoe magnet.



(a)

(b)

FIG. 19.2 Bring a bar magnet near iron filings. The maximum iron filings cling to the end of the bar and practically none at the centre. This indicates that the magnetic properties of a bar magnet are concentrated at its ends.

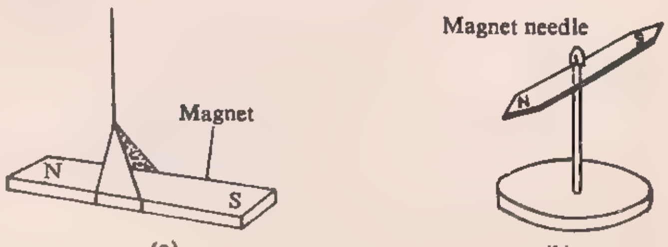
Moving charges produce an effect known as magnetism, which has an important bearing on our life style. This effect is responsible for production of electricity, working of computers, tape recorders, telephones, etc.

19.1 BASIC CONCEPTS

D.19.1 Magnetism A fundamental property of some substances by virtue of which they attract small iron pieces; or a fundamental property by virtue of which a *small* bar possessing this property when suspended freely will always align itself in the north-south direction.

NOTE All material bodies are made up of molecules and atoms, which contain electrons. An electron is constantly moving around and has two types of motion within the atom.

(i) An orbital motion around the nucleus.
(ii) A spinning motion (like the earth's rotation about its own axis).



(a) (b)

FIG. 19.3 A bar magnet allowed to rotate freely about a vertical axis always comes to rest in that position in which its ends point approximately towards the geographical north and south poles of the earth.

These two types of movements of the electric charge on an electron give rise to magnetism. Similarly, when charge flows in a conductor a magnetic effect is produced. There is *no* magnetic effect associated with a stationary electric charge.

D.19.2 Magnet A body or apparatus which can produce magnetic effect.

D.19.3 Poles The regions of strongest magnetism inside a magnet.

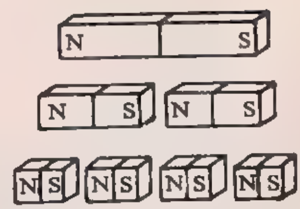


FIG. 19.4 Cutting a magnet into two pieces. Each piece acts as a magnet having N and S poles in the same orientation as the original magnet.

TYPE OF POLES

Every magnet has two poles.

(*a*) *North pole* The pole of the magnet which points approximately towards the north pole of the earth when the magnet is suspended and allowed to rotate freely.

WRITTEN REPRESENTATION N-pole.

(*b*) *South pole* The pole of the magnet which points approximately towards the south pole of the earth when the magnet is suspended and allowed to rotate freely.

WRITTEN REPRESENTATION S-pole.

NOTES (i) Magnetic poles always occur in pairs. So far a single pole has not been isolated, unlike the electric charge.

(ii) The magnetic effect of the two poles that occur together are always equal.

(iii) In commercial magnets, N-pole is painted red and S-pole is painted grey.

(iv) The pole inside a magnet is not a point but a region.

(v) The poles are situated slightly inside the magnet and not exactly at the ends.

D.19.4 Magnetic Force The force which a magnet exerts on a magnetic substance.

NOTE The existence of repulsion is a *sure* test of magnetism. If the given magnetic substance is not a magnet it will always be attracted by a magnet. In case the given bar is a magnet, one end of it will be repelled and the other end will be attracted by a magnet.

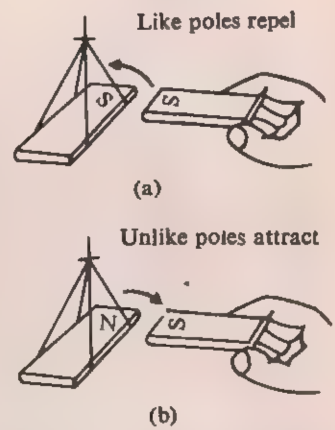


FIG. 19.5 (a) Two like poles of a magnet repel each other. (b) Two unlike poles attract each other.

D.19.5 Magnetic Field The region around a magnet in which it is capable of exerting a force.

NOTE In common usage the word magnetic field is also used to refer to its strength.

D.19.6 Magnetic Line of Force—Field Lines A line in a magnetic field along which a unit positive north pole will move.

FIG. 19.7 The direction of the magnetic field at any point is the direction of the magnetic force on a unit north pole. It is always along the tangent to the line of force at that point (the magnetic needle will point in this direction).

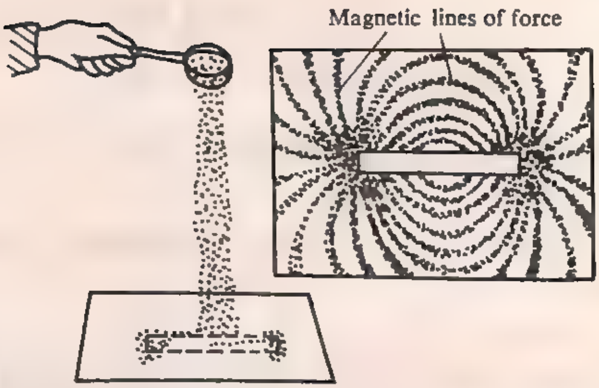


FIG. 19.6 Magnetic lines of force. Place a magnet on cardboard and sprinkle some iron filings on it. On tapping the cardboard gently, the iron filings arrange themselves along lines which are known as magnetic lines of force.

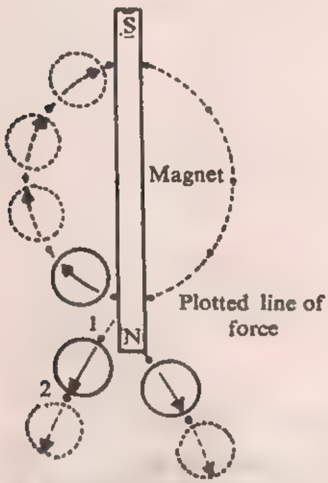


FIG. 19.8 Plotting magnetic lines of force. (a) Take a big sheet of paper and place a magnet over it. Draw a line to mark the position of the magnet. (b) Place a magnetic needle near the north pole and mark by dots (1, 2) the position of the two ends of the needle. (c) Now move the magnetic needle such that its tail is near the point 2. Mark again the position of the two ends of the needle. Continue this till you reach the S-pole of the magnet or the last dot goes out of the paper. Join all the points by a line. This is a magnetic line of force.

PROPERTIES (i) The direction of the lines of force is always taken to be from the north pole to the south pole.

(ii) Two lines of force can never cross each other.

(iii) For a magnet these start normally from one surface and end normally at the other surface.

(iv) The density of lines in any particular region is a measure of the magnetic field strength in that region.

D.19.7 Neutral Points The points in a magnetic field at which the magnetic force is zero.

PICTORIAL REPRESENTATION X

NOTES (i) A neutral point is formed by the interaction of two magnetic fields at a point where the two fields cancel each other.

(ii) For a single magnet, neutral points are formed where the magnet's magnetic field cancels the earth's magnetic field.

(iii) Every magnetic field has at least two neutral points because of its interaction with the earth's magnetic field.

(iv) A magnetic needle placed at a neutral point will not point in any particular direction.

19.2 MAGNETIC EFFECTS OF ELECTRIC CURRENT

For a long time it was thought that electricity and magnetism are two different phenomenon having no connection with each other. The discovery that a magnetic field can be produced by a current carrying wire revolutionized the course of physics (see Fig. 19.10, Oersted experiment).

D.19.8 Electromagnetism The magnetism produced by an electric current.

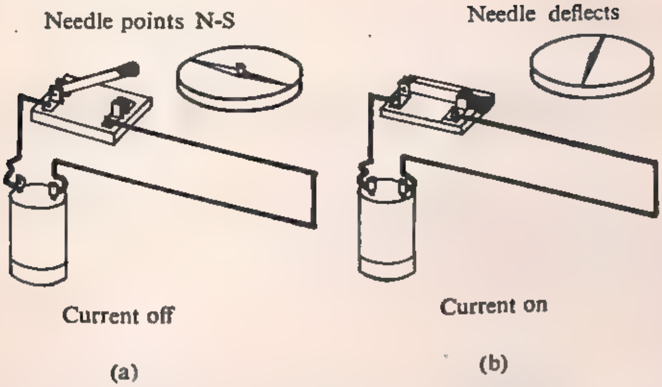


FIG. 19.10 Oersted experiment. (a) A compass needle placed parallel to a wire which does not carry current points north-south. (b) When the current is switched on in the wire, the needle deflects until it almost becomes perpendicular to the wire showing that some force is now acting on it. As the magnetic needle can only be deflected by a magnetic force, the current carrying wire must be producing a magnetic field.

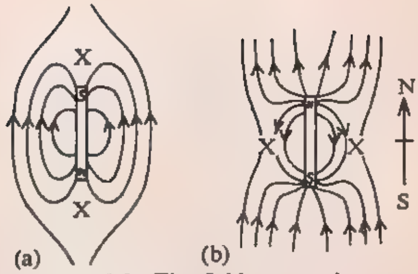


FIG. 19.9 The field pattern due to bar magnet. The point marked X is the neutral point.

D.19.9 Magnetic Field due to a Long Current-Carrying Wire The lines of magnetic force are concentric rings with centre at the wire, Fig. 19.11.

DIRECTION Either from cork screw rule or from Maxwell's right hand grip rule, Fig. 19.12.

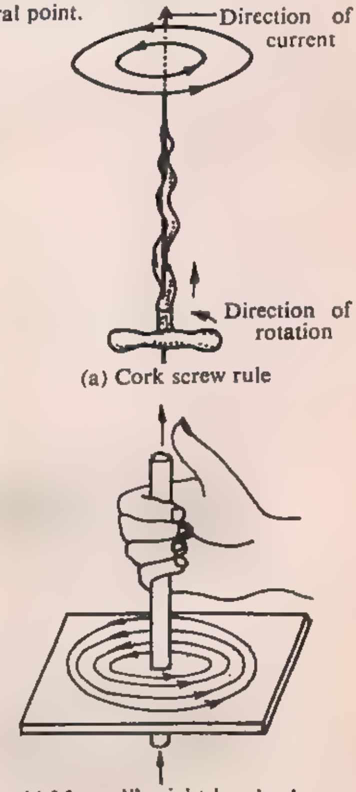


FIG. 19.12 Direction of magnetic lines of force. (a) Cork screw rule. A screw is rotated such that it moves along the direction of the electric current. The direction of rotation of the screw gives the direction of the magnetic lines of force. (b) Maxwell's right hand rule. Grasp the wire in the right hand such that the thumb points in the direction of current. The fingers circling the wire are in the same orientation as the field.

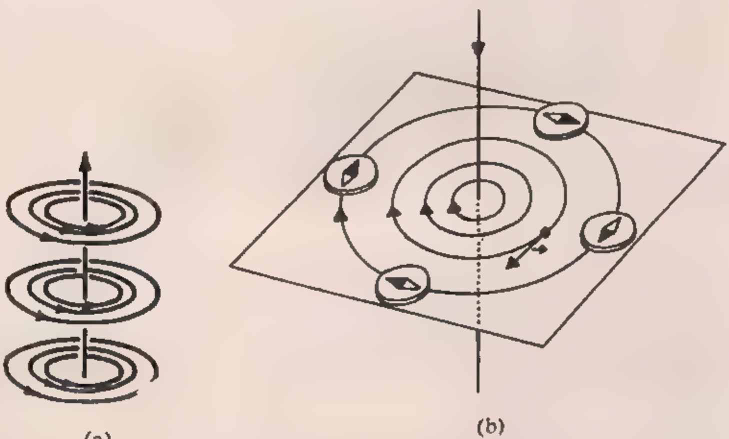


FIG. 19.11 Magnetic field near a current carrying wire. The lines of force are concentric circles.

NOTES (i) The direction of the lines of force depends on the direction of the current in the conductor.

(ii) The extent of the magnetic field depends on the strength of the current.

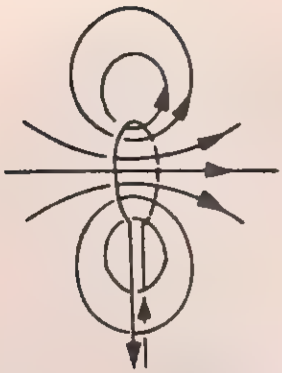


FIG. 19.13 Magnetic line of force due to a circular coil. Near the wire these are concentric circles, and at the centre, these are straight lines.

D.19.10 Magnetic Field due to a Circular Coil The pattern of the magnetic lines of force is shown in Fig. 19.13.

D.19.11 Solenoid A long coil of wire such that its length is great compared to its diameter.

NOTE The wire is wound over a cylinder of nonconducting material.

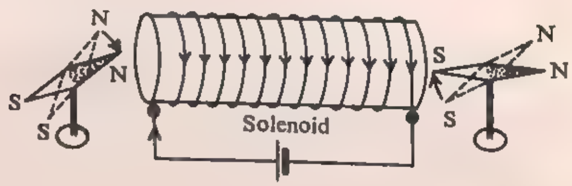


FIG. 19.14 A solenoid.

D.19.12 Magnetic Field due to a Solenoid The magnetic field due to a solenoid is made up of the magnetic fields of a large number of coils in series. The resultant field is similar to that of a bar magnet. See Fig. 19.9(a) and Fig. 19.15 (c).

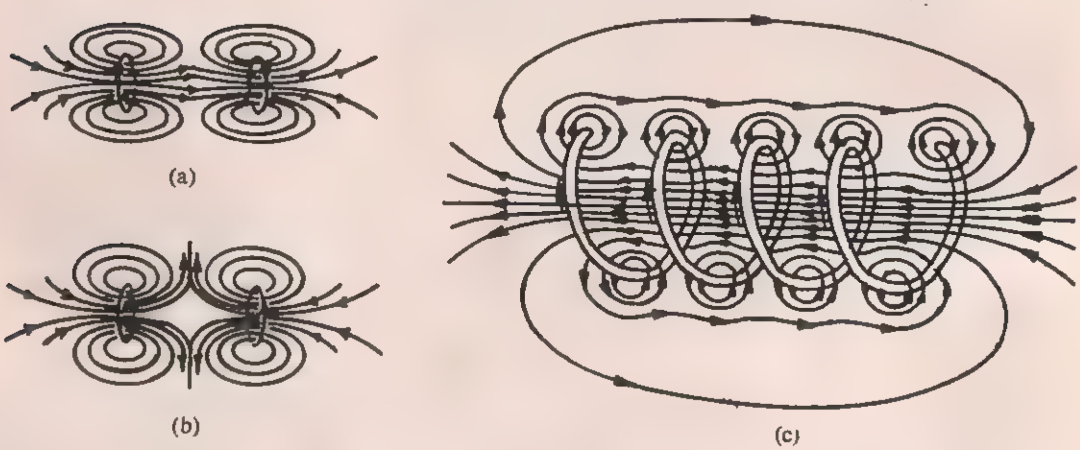


FIG. 19.15 The magnetic field pattern due to two coils, current being in (a) same direction, (b) opposite direction. (c) The field pattern due to a solenoid.

POLARITY OF SOLENOID See Fig. 19.16.

NOTE The strength of the magnetic field depends on the material inside the hollow cylinder. If a bar of soft iron is placed inside the solenoid, the strength of the magnetic field is greatly enhanced.

19.3 ELECTROMAGNETS AND THEIR APPLICATIONS

The phenomenon of electromagnetism has been successfully applied to produce magnets for the duration for which current passes through a conductor. Electromagnets find numerous applications in electric bells, telephones, cranes for lifting objects, etc.

FIG. 19.16 Polarity of a solenoid ends. Look at the end of the solenoid. The end is an S-pole if current is going round the coil in clockwise direction. The end is an N-pole if current is going round the coil in anticlockwise direction.

D.19.13 Core The material over which the wire of a solenoid is wound.

NOTE Usually the material of a core is soft iron because when current is switched off from the solenoid it loses its magnetism completely. If steel is used, it retains some of its magnetism which is not desirable in electromagnet applications.

D.19.14 Armature A body, usually ferromagnetic, mounted so as to be capable of movement in the field of a magnet.

D.19.15 Electric Bell—Buzzer An electrical device using an electromagnet to switch on and off an electrical current thereby activating a mechanism which produces a sound.

CONSTRUCTION See Fig. 19.17.

WORKING PRINCIPLE (Electric bell) when the button is pressed, the electrical circuit is completed and the electromagnet acquires magnetism. The electromagnet attracts the armature and two things happen. The hammer strikes the gong producing sound and the electrical circuit breaks. As soon as the circuit breaks the electromagnet loses its magnetism and consequently the armature returns back completing the circuit again. This process is repeated again and again till the button is not released.

NOTE In a buzzer there is no hammer and gong. The sound is produced by the armature itself.

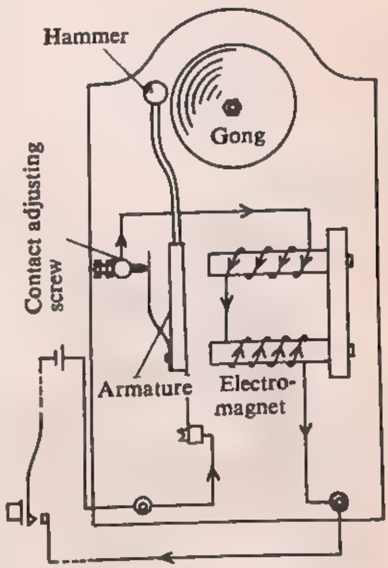
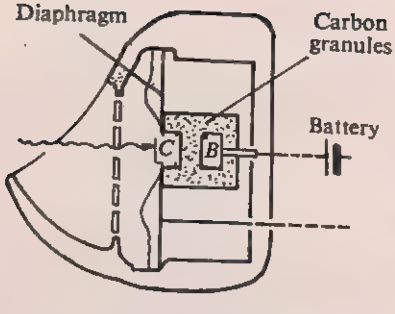


FIG. 19.17 An electric bell. One end of the solenoid wiring is connected to a power supply and the other end to an armature. The armature has a hammer which produces a sound on striking a gong. The armature is in contact with a contact adjusting screw and the power supply.

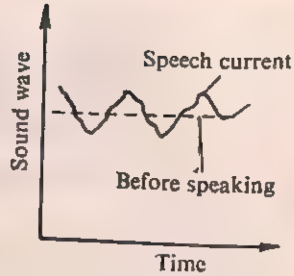
D.19.16 Microphone A device to convert sound energy into electrical energy.

CONSTRUCTION See Fig. 19.18.

WORKING PRINCIPLE The sound waves falling on the diaphragm set it in vibration and the carbon granules are subjected to a variable pressure. When a compression of a sound wave falls on the diaphragm, the distance between the two carbon discs decreases and, from E.18.15, the resistance in the circuit diminishes; consequently the current in the circuit increases. When a rarefaction falls on the diaphragm, the distance between the two carbon discs increases. From E.18.15, the resistance in the circuit increases which lowers the current in the circuit. Thus the sound wave produces a variable current in the circuit. The



(a)



(b)

FIG. 19.18 A microphone. It has two polished carbon discs. One of them, B, is fixed while another, C, is free to move, and is connected to a metal diaphragm. The space between B and C is filled with small carbon granules. A battery is connected across B and C. The sound waves falling on the diaphragm cause C to move to and fro slightly. This produces a variable current in the circuit.

frequency of this current, known as the speech current, which is the output of the microphone, is the same as that of the sound wave.

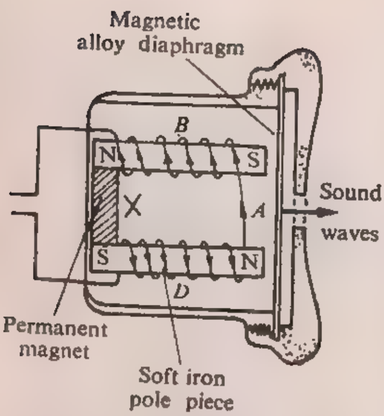


FIG. 19.19 Earphone. It has a U-shaped magnet, formed by placing a small permanent strong bar magnet, X, between two soft iron pole pieces B and D. Two solenoids of thousands of turns of very thin insulated wires are wound in opposite directions over B and D. A springy alloy diaphragm, A, is placed in front of U-shaped magnet. A is attracted by B and D and thus remains in permanent tension.

D.19.17 Earphone A device to convert variable electric current into sound energy.

CONSTRUCTION See Fig. 19.19.

WORKING PRINCIPLE When the variable current (speech current) from a microphone passes through the solenoid, a variable magnetic field is set up in the U-shaped magnet. A variable magnetic force is now exerted on the diaphragm. As a consequence it starts vibrating with the same frequency as that of the current. The vibrating diaphragm reproduces the sound waves falling over the microphone.

D. 19.18 Telephone A device that sends sound signals from one place to another.

CONSTRUCTION See Fig. 19.20.

WORKING PRINCIPLE When the receiver of the telephone is lifted, a switch operates, connecting the microphone to a battery and the primary circuit of a step up transformer. This sets up a steady current in the microphone circuit. When a person speaks in the mouthpiece, the sound waves change the microphone resistance, producing a fluctuating current in the circuit. This in turn gives rise to a fluctuating current in the secondary coil of the step up transformer. These fluctuations are carried to the receiving end. Here the earphone converts the fluctuating current back to sound waves.

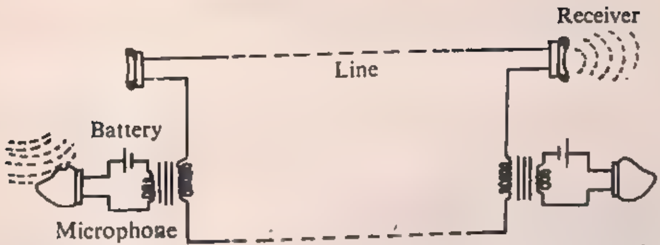


FIG. 19.20 A two way telephone circuit. It contains a receiver having a microphone and an earphone. The microphone is connected to the primary of the step up transformer and a battery. The earphone is connected to the secondary of the transformer. Two sets are connected to each other by lines. The step up transformer is used so that even low intensity sound waves produce appreciable voltage variation in the secondary and the sound energy is amplified before transmission.

19.4 INTERACTION BETWEEN MAGNETIC FIELD AND ELECTRIC CURRENT

We have seen that a current carrying conductor behaves like a magnet. Two current carrying conductors when placed close to each other will, therefore, exert a force on each other. Likewise a current carrying conductor placed in a magnetic field will experience a force. This principle is applied in constructing current measuring devices, electric motors, etc.

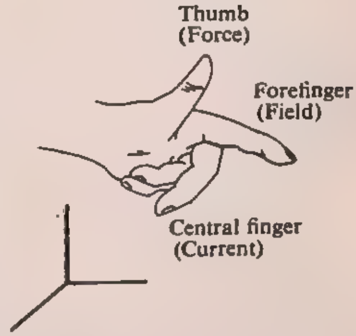


FIG. 19.21 Fleming's left hand rule gives the relative directions of magnetic field, current and force.

D. 19.19 Force Exerted by a Magnetic Field on a Current Carrying Conductor Since a current carrying conductor behaves as a magnet, it experiences a force when placed in a magnetic field.

SPECIFICATION Direction: by Fleming's left hand rule. See Fig. 19.21.

MATHEMATICAL EXPRESSION

$$
\begin{aligned}
F &\propto I \\
&\propto L \\
F &= B\,I\,L \qquad (E.19.4)
\end{aligned}
$$

where B is a constant.

(a) Uniform field (b) Field of current (c) Resultant field

FIG. 19.22 (a) Uniform field of a magnet. (b) Field due to a current carrying wire. (c) The magnetic field pattern, being the resultant of (a) and (b), due to a current carrying wire at right angles to a uniform field. The lines of force are more on one side of the wire than on the other side. This implies that the field is stronger on one side of the wire. Hence a resultant sideways force will act on the wire.

NOTE If the wire is parallel to the magnetic field, the force is zero. The force is maximum when the wire is perpendicular to the magnetic field.

D. 19.20 Magnetic Induction A measure of the magnetic field strength.

TYPE OF QUANTITY Vector

WRITTEN REPRESENTATION **B**

SPECIFICATION The force experienced by a conductor of length 1 metre carrying a current of 1A when placed in the magnetic field at right angles to the direction of the field. Measured in newton per ampere per metre ($NA^{-1}\,m^{-1}$ = Tesla).

D. 19.21 Force between Two Current Carrying Wires Two current carrying conductors when placed close to each other exert a force on each other.

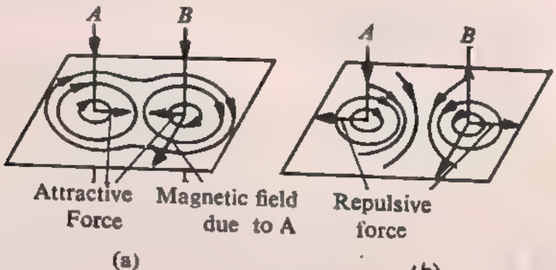


FIG. 19.23 Force between two wires. The lines of force due to a straight wire are concentric rings. At the other wire the magnetic force is along the tangent to the circle. At point A in (a) the force is attractive and (b) the force is repulsive.

SPECIFICATION Direction: by Fleming's left hand rule.

MAGNITUDE See E. 19.1.

MATHEMATICAL EXPRESSION

$$F = \frac{\mu}{2\pi}\,\frac{I_1 I_2 L}{r} \qquad (E.\ 19.1)$$

D. 19.22 Ampere E. 19.1 can be used to define current. If $r = 1$ m, $I_1 = I_2 = 1$ A and $L = 1$ m then

$$F = 2 \times 10^{-7}\ \text{N}.$$

Thus ampere is defined as 'the magnitude of the constant current, which if maintained in two parallel rectilinear conductors of infinite length and of negligible circular cross-section, placed at a distance of one metre from each other in vacuum, will produce between the conductors a force equal to 2×10^{-7} newton per metre of length'.

D. 19.23 Galvanometer A sensitive device to measure or detect small currents.

WORKING PRINCIPLE See Fig. 19.24.

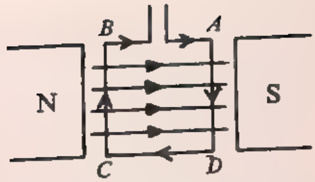


FIG. 19.24 Principle of a galvanometer. A rectangular coil *ABCD* is placed inside a uniform magnetic field. When a current is passed through the coil, the force on the sides *AB* and *CD* is zero because these are parallel to the magnetic lines of force. The force on the side *AD* is upward and on *BC* downward, by Fleming's left hand rule. Since the two forces are equal, a couple is formed which rotates the coil.

TYPES OF GALVANOMETERS

(*a*) *Suspended coil galvanometer*

CONSTRUCTION See Fig. 19.25.

WORKING PRINCIPLE The current passing through the coil produces a couple rotating the coil which in turn twists the phosphor bronze wire. When the torsion couple in the phosphor bronze wire due to its elasticity equals the couple due to the current in the coil, the mirror stops rotating. The rotation in the wire can be accurately measured.

NOTE Usually the coil is wound on a nonmetallic frame.

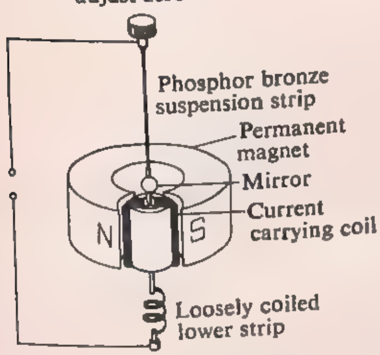


FIG. 19.25 Suspended coil galvanometer. A rectangular coil moves freely in the annular space formed by placing a soft iron piece between the two poles of a permanent horse shoe magnet. The ends of the coil are soldered to two stiff wires. The coil is suspended by a phosphor bronze wire which in turn is attached to a torsion head.

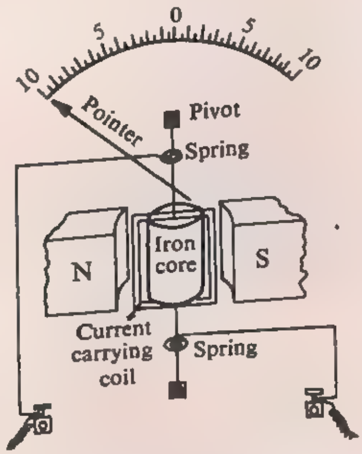


FIG. 19.26 Pivoted coil galvanometer. The ends of a coil, which is wound on a light aluminium frame, are joined to a pivot with jewelled end bearings. One end of the coil carries a pointer which moves over a scale. The counter couple is provided by two phosphor bronze springs.

(*b*) *Pivoted coil galvanometer*

CONSTRUCTION See Fig. 19.26.

WORKING PRINCIPLE Similar to the suspended coil galvanometer. Here when the coil rotates the needle moves on the scale.

D. 19.24 Ammeter A pivoted type galvanometer calibrated to read current strength.

NOTES (i) An ammeter is always connected in series in a circuit.

(ii) An ideal ammeter has zero resistance. Therefore, its presence does not change the current in the circuit.

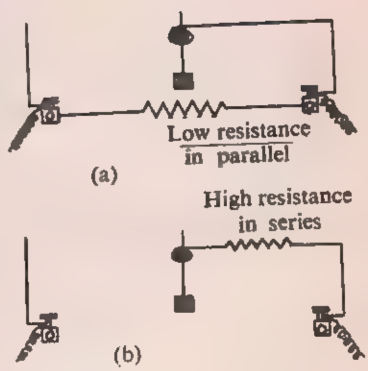


FIG. 19.27 (a) Ammeter. It is a pivoted type galvanometer with a low resistance in parallel with the terminals. The total resistance of the ammeter is very small. (b) Voltmeter. It is a pivoted type galvanometer with resistance in series.

D. 19.25 Voltmeter A pivoted type galvanometer calibrated to read potential difference between two points.

NOTES (i) A voltmeter is always connected in parallel to the circuit element.

(ii) An ideal voltmeter has infinite resistance. Therefore it does not draw any current, and hence does not change the potential difference between two points.

D. 19.26 Electric Motor A device to convert electrical energy into kinetic energy.

CONSTRUCTION See Fig. 19.28.

WORKING PRINCIPLE Suppose that the coil is initially in position (a). The plane of the coil is perpendicular to the magnetic field. The forces in the two arms of the coil are opposite to each other, and hence a couple is formed which rotates the coil till position (b) is reached. In this position the brushes touch the space between the two commutators and hence no current flows through the coil. The coil keeps on moving due to inertia. In position (c) the ends of the coil change polarity. Again there is a clockwise couple on the coil which rotates it in the same direction. Thus the coil keeps on rotating as long as current flows through it.

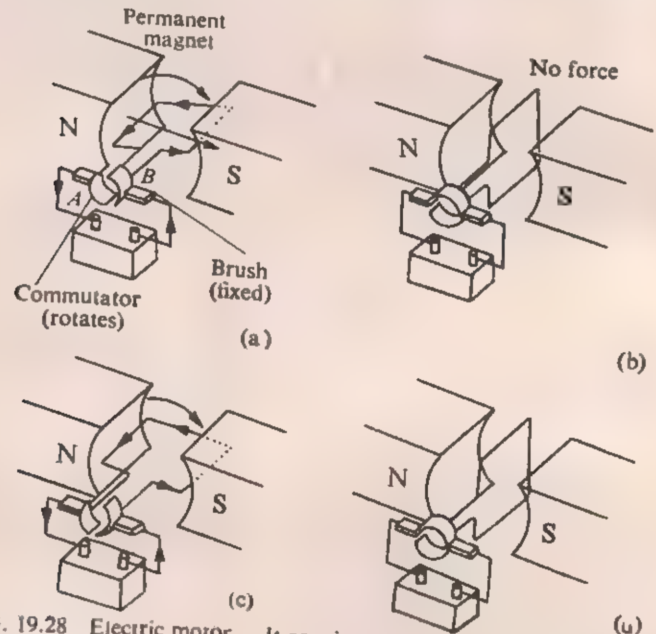


FIG. 19.28 Electric motor. It consist of a powerful magnet (either permanent or an elecromagnet). A rectangular coil made from insulated copper wire, wound on an armature capable of moving freely is placed inside the magnetic field. The two free ends of the coil are soldered to the two halves A, B of a commutator. The current is supplied to the carbon brushes which are in contact with the commutator through light springs.

SOLVED EXAMPLES

$\left(\textit{Note}\text{ wherever necessary take } \frac{\mu_0}{2\pi} = 2\times 10^{-7}\,\mathrm{NA^{-2}}\right)$

EXAMPLE 19.1 A magnet is placed vertically over a paper. If the lines of force enter the paper from above, at a distance from the magnet, which pole of the magnet is placed over the paper?

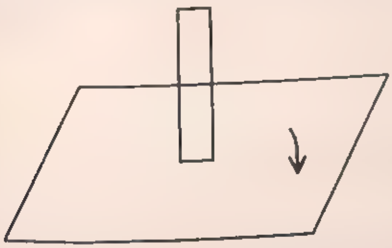


FIG. 19.29 For Example 19.1

Solution By definition, the magnetic lines of force travel from the north to the south pole. According to the question the lines of force are entering the paper. Thus the pole placed over the paper should be a south pole.

Answer The pole placed over the paper is a south pole.

EXAMPLE 19.2 What will be the magnitude and direction of the magnetic field if a wire 15 cm long carrying a current of 5 A in the south-north direction experiences a force of 3×10^{-2} N towards the east?

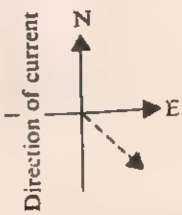


FIG. 19.30 For Example 19.2

Solution $I = 5$ A, $l = 15$ cm $= 0.15$ m and $F = 0.03$ N. The magnitude of the force on the current carrying wire is given by

$$F = BIl$$

$$\text{or,}\quad B = \frac{F}{Il} = \frac{0.03\ \mathrm{N}}{5\ \mathrm{A}\times 0.15\ \mathrm{m}} = 0.04\ \text{Tesla}$$

The direction of the field can be obtained by using Fleming's left hand rule. Hold your left hand in such a way that the central finger, fore-finger and the thumb are at right angles to each other. Point the central finger towards the direction of current, the thumb towards the direction of force. Then your forefinger points in the direction of the field. In this case the field is in a direction perpendicular to the plane of the paper and coming out of it.

Answer The magnitude of the magnetic field is 0.04 Tesla and is perpendicular to the plane of the paper and coming out of it.

EXAMPLE 19.3 Two parallel wires carrying equal currents exert a force of 4×10^{-5} N on each other. If the length of the wires is 5 cm and the distance between them is 10 cm, determine the magnitude of the current. When will the force be attractive?

Solution $F = 4\times 10^{-5}$ N, $L = 5$ cm $= 0.05$ m, $r = 10$ cm $= 0.1$ m. According to the question $I_1 = I_2 = I$. We know that,

$$F = \frac{\mu_0}{2\pi}\,\frac{I_1 I_2 L}{r},$$

$$\text{or}\quad I^2 = \frac{2\pi F r}{\mu_0 L} = \frac{4\times 10^{-5}\ \mathrm{N}\times 0.1\ \mathrm{m}}{2\times 10^{-7}\ \mathrm{NA^{-2}}\times 0.05\ \mathrm{m}}$$

$$= 400\ \mathrm{A^2}$$

$$I = 20\ \mathrm{A}.$$

The force will be attractive when the current in both wires is in the same direction.

Answer The current in each wire is 20 A. The force will be attractive if current in both the wires flows in the same direction.

EXAMPLE 19.4 In an electric power line, a current of 20 A is flowing from east to west direction. Determine the direction of the magnetic field above and below the power line.

Solution The direction of the current is obtained by applying the right hand thumb rule. We see from Fig. 19.31 that for points above the power line the magnetic field is towards north into the plane of the paper and for points below the power line, it is towards south coming out of the plane of the paper.

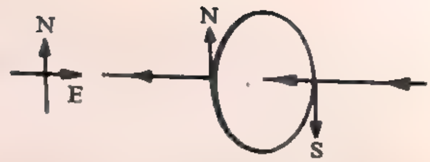


FIG. 19.31 For Example 19.4

Answer For points above the power line it is towards north into the plane of paper and for points below the power line it is towards south coming out of the plane of the paper.

PROBLEMS

19.1 What is the direction of the magnetic field above a straight wire which carries a current due south?

19.2 A wire carries a current of 2A due west. It passes through a region of magnetic field intensity 10^{-2} T along the north south direction. Determine the magnitude and the direction of force. The length of the wire in the magnetic field is 10 cm.

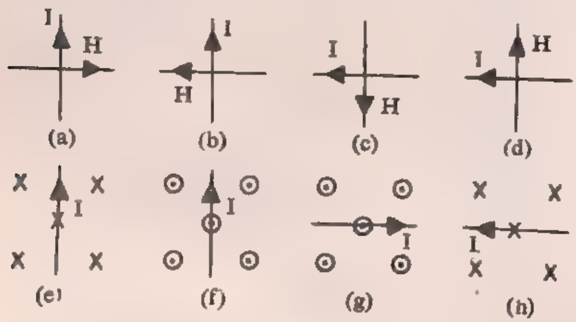


FIG. 19.32

19.3 Find the direction of force in each of the cases in Fig. 19.32.

19.4 A wire is supported horizontally in a north-south direction and a compass needle is placed below it. In which direction will the needle deflect if a current is passed along the wire towards the north?

19.5 The direction of a magnetic field in a horizontal plane is from west to east. A wire is placed vertically in this field. If the current is flowing upwards, find the direction of force on the wire.

19.6 At one end of a solenoid the direction of current is as shown. Is it the north or the south pole?

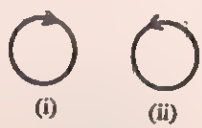


FIG. 19.33

20 Electron

An electron is the lightest material particle. It is a constituent of the atom, where it rotates round the nucleus in fixed orbits. It is responsible for the flow of current in circuits, for the formation of various atoms, emission of light from atoms, etc.

20.1 BASIC CONCEPTS

D. 20.1 Discharge The phenomenon of passage of electric current through nonconductors.

EXAMPLE A charged body placed in air (nonconductor) loses its charge slowly.

D. 20.2 Discharge Tube A glass tube having two electrodes with an arrangement to control the pressure of gas inside it.

CONSTRUCTION See Fig. 20.1.

FUNCTION To study the electric discharge through gases.

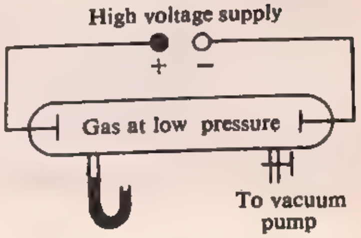


FIG. 20.1 Discharge tube is an apparatus to study discharge of electricity through gases. It consists of a glass tube about 20 cm long and 3 cm in diameter and has two electrodes. A potential difference of about 2000 V to 3000 V is applied. The tube is connected to a vacuum pump.

20.2 DISCHARGE THROUGH GASES

Normally, at atmospheric pressure, gases are bad conductors of electricity. But at low pressure and at a high potential difference, charge can flow through them. Depending on the pressure of the gas, the following phenomena are observed.

1. *Atmospheric pressure* No discharge takes places.
2. *Pressure about 20 mm of Hg* The two electrodes are joined by one or more wavy violet streamers.
3. *Pressure less than 20 mm of Hg* The streamers broaden out into a luminous column, known as *positive column*. It completely fills the tube between the two electrodes.

NOTES (i) The colour of the positive column depends on the

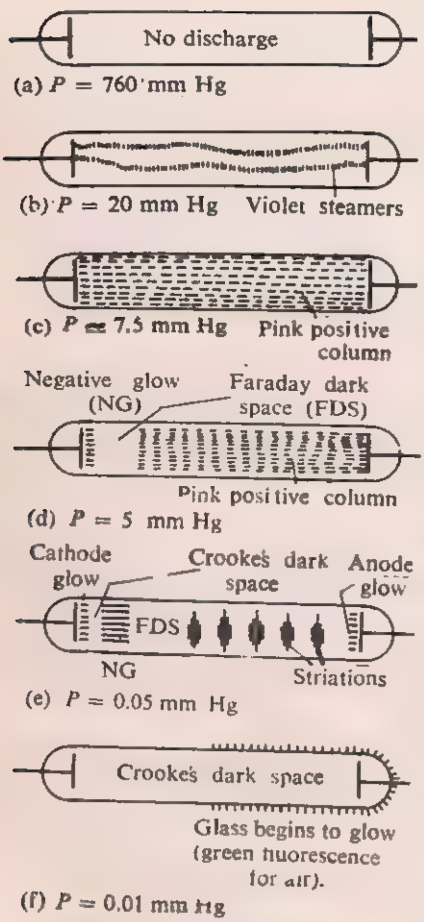


FIG. 20.2 The discharge of electricity at different pressures

gas. Salmon pink—air, bright red—neon, green—helium, blue—hydrogen, white—mercury vapour.

(ii) The colourfully lit advertising sign-boards are really partially evacuated gas filled tubes.

4. *Pressure about 5 mm of Hg* The positive column divides into two parts.

A glow appears near the cathode. It is known as the *negative glow* (NG). There appears a dark space, known as *Faraday dark space* (FDS), between the negative glow and the positive column.

NOTE The sizes of FDS and positive column depend only on the pressure and not on the nature of the gas or length of the tube.

5. *Pressure less than 5 mm of Hg* The positive column shrinks and breaks into striations.

The negative glow detaches from the cathode and increases in size.

Another glow, known as *cathode glow* (CG), appears on the cathode.

The dark space between the cathode and the negative glow is known as *Crooke's dark space* (CDS).

6. *Pressure about 0.01mm of Hg* Crooke's dark space fills the tube completely and the glass begins to glow.

NOTE The tube glows because when the cathode rays (D. 20.4) strike the glass, it emits light due to flourescence (D. 20.3).

7. *Pressure about 10^{-4} mm of Hg* No discharge passes through the tube, as there are not enough gas molecules left to carry the charge.

D. 20.3 Flourescence The phenomenon in which, when light or energetic particles fall on certain substances, these start emitting light.

D. 20.4 Cathode Rays The streams of particles shot out by the cathode when the Crooke's dark space in a discharge tube completely fills the tube. (Cathode rays consist of electrons.)

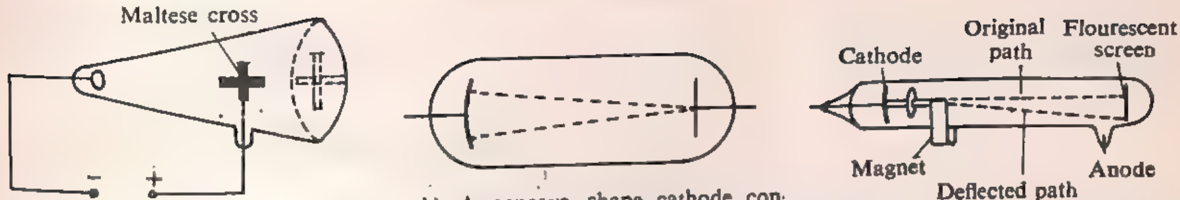
PRODUCTION Cathode rays are produced in a discharge tube when the pressure is about 10^{-2} to 10^{-3} mm of Hg, and the potential difference between the electrodes is about 2000-3000 V.

PROPERTIES See Fig. 20.3.

D. 20.5 Thomson Experiment An experiment designed to measure the ratio of electric charge to mass of cathode rays (electrons).

The experiment is performed in three steps. See Fig. 20.4.

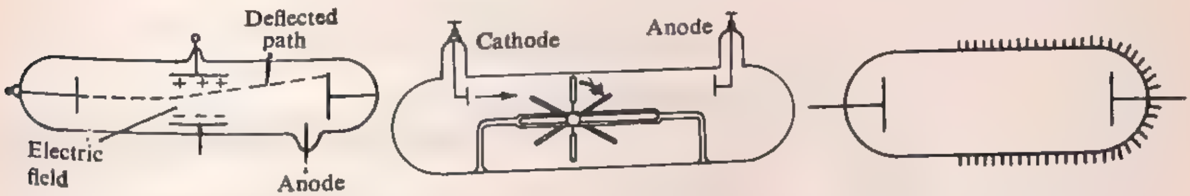
CONCLUSIONS (i) $e/m = 1.76 \times 10^{21}$ C kg^{-1}. It is independent of the nature of the cathode and the gas inside the discharge tube.



(a) Cathode rays travel in straight lines and cast a sharp shadow of an object placed in its path.

(b) A concave shape cathode concentrates these to a point, the focus of the concave mirror. This demonstrates that cathode rays are emitted normally from the cathode surface.

(c) They are deflected by the magnet The direction of deflection suggests that these are negatively charged particles



(d) They are deflected by the electric field towards the positive plates, suggesting that they carry negative charge.

(e) These carry momentum. On passing the discharge the paddle wheel rotates towards the anode.

(f) They produce fluorescence. The colour of light emitted depends on the substance used.

FIG. 20.3 Properties of cathode rays. (g) They have energy. A piece of metal placed at the focus of a concave cathode melts. (h) They can affect photographic plates.

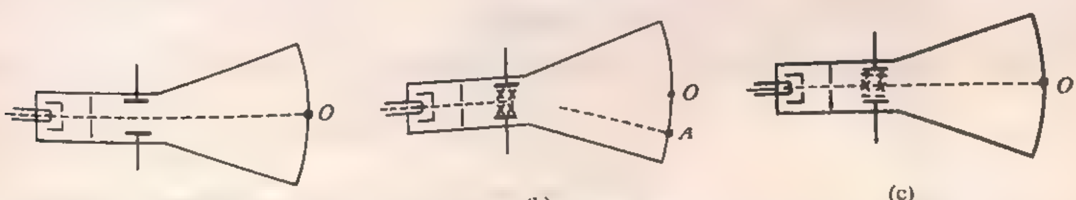
(ii) The velocity of cathode rays is 29 000 km s^{-1}.

NOTE You will learn how to arrive at these conclusions in higher classes.

20.3 THERMIONIC EMISSION AND VACUUM TUBES

D. 20.6 Free Electrons—Mobile Electrons The electrons which move freely inside the volume of a metal.

NOTE An atom of a metal has a large number of electrons which revolve around the nucleus in orbits. The electron which



(a) (b) (c)

FIG. 20.4 Thomson's experiment is performed in three steps.
(a) A fine beam of cathode rays is obtained, which gives a bright spot at the centre of a fluorescent screen.
(b) A magnetic field is set up either by current carrying wires inside the tube or by bar magnets placed outside the tube. The cathode rays are deflected and a spot is formed at point A.
(c) An electric field is applied and the strength of it is adjusted such that the deflection produced by the electric field cancels the deflection produced by the magnetic field. The spot returns to the point O.

is farthest from the nucleus experiences a very weak force and hence does not remain attached to any particular nucleus. It moves freely inside the volume of the metal.

D.20.7 Work Function The minimum amount of energy which must be supplied to free electrons of a metal to enable them to escape from the metal surface.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION ϕ

SPECIFICATION Measured in joule (J).

NOTE The electrons at the surface of the metal are pulled down by the positive charge of the nucleus. Energy must be supplied to overcome this attractive force.

D.20.8 Thermionic Emission The phenomenon of emission of electrons from a solid body (especially from metals) as a result of its temperature.

CAUSE Inside a metal there are a large number of free electrons. When the metal is heated, the kinetic energy of the electrons increases. As soon as their kinetic energy becomes greater than the work function, they escape from the metal surface.

NOTE The rate of emission depends on the temperature and nature of metal. The rate is fast for cesium, slower for tungsten and quite slow for platinum.

D.20.9 Valve A device which allows fluid or electric current to flow in one direction only.

D.20.10 Vacuum Tube—Electronic Valve A device in which two or more electrodes are enclosed in an envelope commonly made of glass. The tube is almost completely evacuated.

D.20.11 Cathode The negatively charged electrode in a vacuum tube which on heating emits electrons, Fig. 20.5.

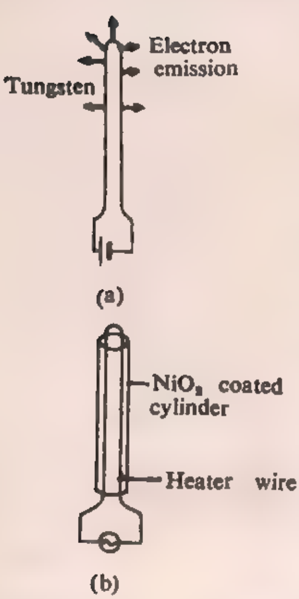


FIG. 20.5 Types of cathodes. (a) Directly heated and (b) indirectly heated. The working temperature of the latter is much less than the former, but the rate of emission is much more.

TYPE OF CATHODES

(a) *Directly heated type* In this, the electric current is passed through the electrode itself. The current heats the cathode. When the temperature is sufficiently high, electrons are emitted from the cathode.

NOTE . Such cathodes are made of tungsten. However, they are not in use nowadays.

(b) *Indirectly heated type* In this, a cylinder of nickel is coated with iron oxide. Current is passed through a filament housed inside the cylinder. The heat of the filament raises the temperature of the cylinder which then emits electrons.

D.20.12 Direct Current The current in a circuit which does not vary and does not change its direction with time.

WRITTEN REPRESENTATION DC

EXAMPLES The current used in transistor radios, torch lights, cars, etc. supplied by cells.

NOTE Upto about 1950 the domestic power supply in India was mostly DC.

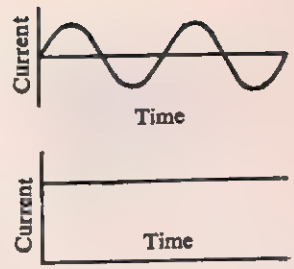


FIG. 20.6 (a) Alternating current. The current varies with time and changes direction. (b) Direct current. The current flows only in one direction.

D.20.13 Alternating Current The current in a circuit which varies and changes its direction with time (see Fig. 20.6).

WRITTEN REPRESENTATION AC

EXAMPLES The current supplied to our homes.

NOTES (i) The maximum and minimum values of current are always equal in magnitude.

(ii) The frequency of domestic AC supply is 50 Hz, i.e. it changes its direction 50 times per second.

D.20.14 Diode A vacuum tube which has only two electrodes, cathode and anode. See Fig. 20.7.

Or

An electronic component which converts AC into DC.

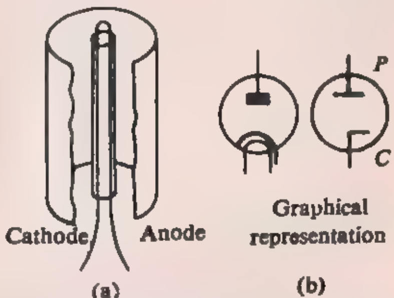


FIG. 20.7 A diode. (a) It has two electrodes, the plate and the indirectly heated cathode. Electrons are emitted by the cathode and are collected by the anode. The two electrodes are enclosed in a glass envelope which has a high degree of vacuum. (b) Graphical representation of the diode.

D.20.15 Diode Characteristics A graph between anode current and potential difference between anode and cathode. See Fig. 20.8.

EXPLANATION OF DIODE CHARACTERISTICS

(a) *When anode is negative* The electrons emitted by the cathode are repelled back by the anode. Hence I_a is zero.

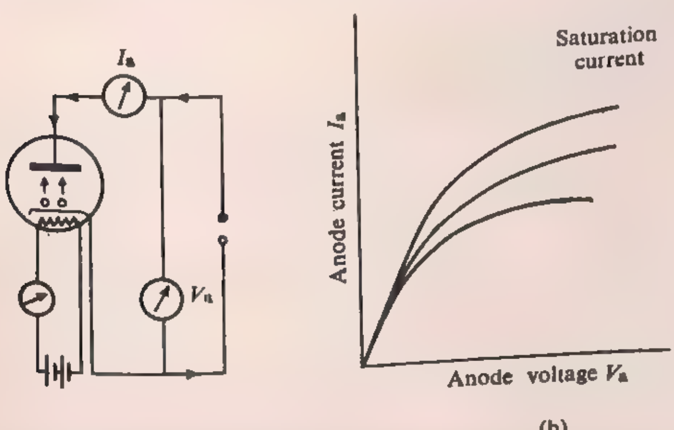


FIG. 20.8 (a) Circuit diagram for plotting diode characteristics. (b) Diode characteristics.

(b) *When $V_a = 0$* The electrons emitted by the cathode are collected in the space between anode and cathode (space charge D.20.16). These electrons in turn repel electrons emitted by the cathode; hence no electrons reach the anode. I_a is zero.

(c) *Anode is positive* Due to the positive anode some electrons are attracted towards the anode and current flows in the circuit. As the anode potential increases, more and more electrons reach the anode and I_a increases. The current becomes maximum when the anode collects electrons as fast as they are emitted by the cathode. This maximum current is known as *saturation current*.

(d) If the current in the filament is increased, the cathode temperature will also increase and more electrons will be emitted. In this case more electrons will reach the anode and the saturation current will increase.

D.20.16 Space Charge The cloud of electrons which exists between anode and cathode.

CAUSE Electrons are emitted from the cathode with varying speeds. The faster moving electrons are collected by the plate but the slower electrons stop in between. In due course of time a substantial number accumulate, forming the space charge.

D.20.17 Rectification The phenomenon in which an alternating current is converted into *unidirectional current*.

NOTE In most of the cases, the current after rectification is strictly not DC because the magnitude of rectified current does vary with time. We therefore have a unidirectional current instead of DC.

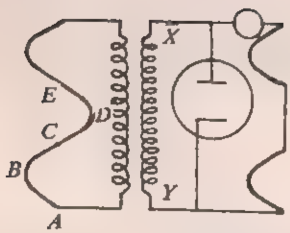


FIG. 20.9 Diode as half wave rectifier.

D.20.18 Rectifier An electrical device which permits current to flow in only one direction, thus converting alternating current into unidirectional current.

DIODE AS RECTIFIER (Half wave)

The device where one half of the AC energy is converted into unidirectional energy is known as a half wave rectifier.

CIRCUIT DIAGRAM See Fig. 20.9.

EXPLANATION (a) Let the point X in Fig. 20.9 be at zero potential (point A of Fig. 20.9). With time X becomes more and more positive, i.e. the anode becomes positive. The current I_a also increases or V_{GH} increases till the point B is reached. After this V_{GH} and I_a decrease and become zero when the point C is reached.

(b) For the portion of graph CDE, point X as well as the anode are at negative potential. No current will flow through the circuit; V_{GH} remains zero during this time.

(c) This process continues and in the circuit, though the current varies with time, it remains unidirectional.

NOTE The device which converts the full AC energy into unidirectional energy is called a *full wave rectifier*.

D.20.19 Triode Valve An electrical valve with three electrodes, cathode, grid and anode. See Fig. 20.10.

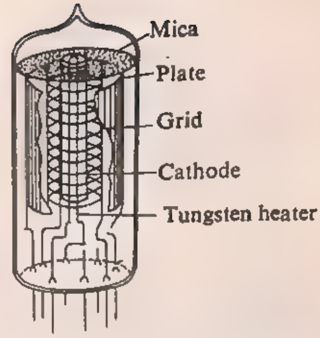


FIG. 20.10 (a) A triode valve. It has three electrodes, cathode, plate and a wire screen between cathode and plate. Grid does not obstruct the flow of electrons. (b) Pictorial representation of the triode valve.

D.20.20 Grid A wire screen between cathode and plate.

FUNCTION To reduce space charge and thus to control the flow of current between cathode and anode.

NOTE There may be more than one grids. A tetrode has two grids, while a pentode has three grids.

D.20.21 Mutual Characteristics A graph between grid potential and plate current at constant plate voltage and cathode current. See Fig. 20.11.

EXPLANATION (a) When the grid is sufficiently negative (point *A* of Fig. 20.11b), all the electrons emitted by the cathode are repelled back to the cathode. Since no electron reaches the plate, $I_a = 0$.

(b) When the grid potential is greater than V_{g1} but less than 0, the faster moving electrons get past it. Once these are between grid and anode they are collected by the anode. Here I_a is non zero and depends on V_g.

(c) For $V_g = 0$, it is like a diode.

(d) When V_g is positive, the electrons are attracted by the grid. Due to this attractive force, they are accelerated and casily reach the anode. As V_g increases, more and more electrons reach the plate or I_a increases.

(e) I_a keeps on increasing till all the electrons emitted by the cathode reach the anode. Further increase in V_g does not increase I_a. This maximum current is known as *saturation current*.

NOTES (i) In the straight portion of the graph, a small change in V_g changes I_a by a large amount.

(ii) There are other kinds of characteristic graphs as well. The anode characteristics show the variation of I_a with V_a.

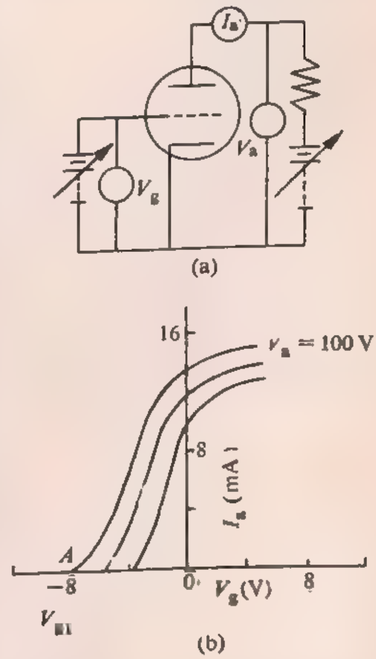


FIG. 20.11 Mutual characteristics of a triode valve. (a) Circuit diagram for plotting triode characteristics. (b) Mutual characteristics of a triode valve. Here the grid potential is changed and the plate current is studied. The plate potential is kept constant for one set.

D.20.22 Amplification The process in which the strength of a signal is increased.

D.20.23 Amplifier An electronic device which increases the strength of a signal fed into it by obtaining power from a source other than the input signal.

TRIODE AS AMPLIFIER The input signal is fed into the grid-

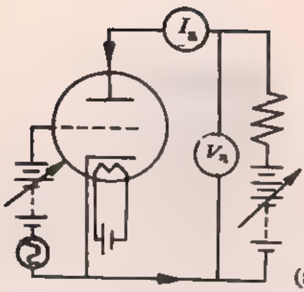
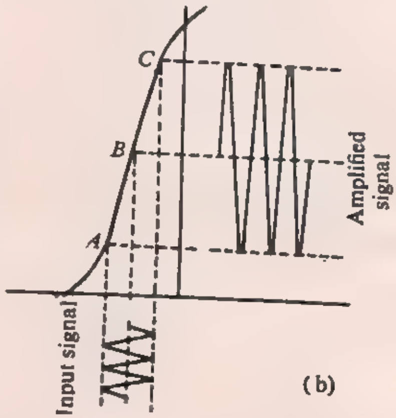


FIG. 20.12 (a) Circuit diagram for triode valve as an amplifier. (b) For operating triode valve as amplifier the grid is kept at a constant potential corresponding to a point on the straight line portion of the mutual characteristic graph (Fig. 20.11b). The input signal is always fed into the grid cathode circuit.

cathode circuit, Fig. 20.12a. The grid is kept at a slightly negative potential corresponding to point B of Fig. 20.12b. Due to the input signal, the grid potential varies between the values corresponding to the points A and C. The current in the plate-cathode circuit varies as shown in Fig. 20.12b. The signal is increased in strength.

NOTE In amplification the energy is supplied by the battery in the plate-cathode circuit.



21 Household Electricity

In households, energy is frequently used in two forms: chemical energy, e.g. burning of gas, wood, oil, etc., and electrical energy. The source of electrical energy is electricity. It is convenient to use, cheap and free of pollution. Today, a large number of gadgets we use to make our life comfortable, operate on electricity.

21.1 BASIC CONCEPTS

D.21.1 Work Done in an Electrical Circuit The work done in moving electrons through a resistor or conductor from a region of lower potential to one of higher potential.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION W

SPECIFICATION The amount of work done in moving a positive charge from a higher potential to a lower potential or a negative charge from a lower potential to a higher potential. Measured in Joules (J).

MATHEMATICAL EXPRESSION From the definition of potential difference (D.18.13),

$$V = \frac{W}{Q} \qquad (E.21.1)$$

Three forms of this equation are frequently used to indicate work done.

$$W = VIt \qquad (Q = I\,t) \qquad (E.21.2)$$

$$= V^2t/R \qquad (E.21.3)$$

$$= I^2Rt \qquad (E.21.4)$$

NOTE The source of electric current does work because electrons have to be moved from one point to another in a circuit.

D.21.2 Power Spent in Electrical Circuit A measure of the energy spent in a certain time.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION P

SPECIFICATION The rate of doing work or rate of expending power. Measured in watt (W).

MATHEMATICAL EXPRESSION

$$\text{Power} = \frac{\text{work done}}{\text{time}}$$

$$= VQ/t = VI \qquad (E.21.5)$$

$$= V^2/R \qquad (E.21.6)$$

$$= I^2R \qquad (E.21.7)$$

NOTE In common usage the word 'wattage' is often used to denote power.

D.21.3 Watt-Hour A unit of work or energy.

TYPE OF QUANTITY Derived SI unit.

WRITTEN REPRESENTATION Whr

SPECIFICATION The amount of energy spent in one hour at the rate of one joule per second or energy equal to one watt operating for one hour.

MATHEMATICAL EXPRESSION

$$\text{Whr} = 1\text{ W} \times 1\text{ hr} = 1\text{ J s}^{-1} \times 3600\text{ s}$$

$$= 3600\text{ J} \qquad (E.21.8)$$

NOTE Watt is the unit of power whereas watt-hour is the unit of energy.

D.21.4 Kilowatt-Hour A practical unit of energy.

TYPE OF QUANTITY Derived SI unit.

WRITTEN REPRESENTATION kWh

SPECIFICATION The amount of energy spent in one hour at the rate of 1000 joules per second or energy equal to 1000 watts operating for one hour.

MATHEMATICAL EXPRESSION

$$\text{kWh} = 1000\text{ W} \times 1\text{ hr}$$

$$= 1000\text{ J s}^{-1} \times 3600\text{ s}$$

$$= 3.6 \times 10^6\text{ J} \qquad (E.21.9)$$

NOTE The unit of electricity in which electrical consumption in households is measured, is kWh.

21.2 HOUSEHOLD ELECTRICAL CIRCUITS

D.21.5 Live Wire—Hot Wire The wire in the electrical network which carries current.

WRITTEN REPRESENTATION L

SPECIFICATION By convention the live wire is always red in colour.

D.21.6 Neutral Wire—Cold Wire The wire which returns the current back to the supply system.

WRITTEN REPRESENTATION N

SPECIFICATION By convention the neutral wire is always black in colour.

NOTES (i) The potential difference between live and neutral wire is equal to the line voltage. (~220 V in India. In some countries the line voltage is 110 V.)

(ii) The neutral wire is at zero potential relative to the live wire.

D.21.7 Earth Wire The wire which connects the body of an appliance to earth.

WRITTEN REPRESENTATION E

SPECIFICATION By convention the earth wire is always green in colour.

NOTE By convention, in a three pin socket, the right hole is for the live wire, the left hole for the neutral and the upper hole which is the largest, for the earth. The same convention is also true for a three pin plug.

D.21.8 Fuse A safety device to protect the electric wiring or electrical appliance from damage due to excessive flow of current.

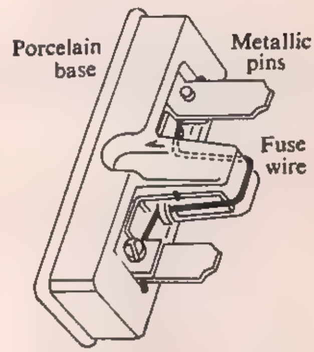
CONSTRUCTION See Fig. 21.1.

WORKING PRINCIPLE The fuse allows current to flow in the circuit so long as its value is less than the fuse rating (D.21.9). When the current in the circuit exceeds the fuse rating, the fuse wire melts, breaking the electrical circuit, thereby disconnecting the appliance from the circuit.

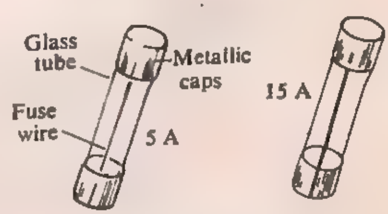
NOTES (i) The fuse is always connected to the live wire. If it is connected to the neutral wire, the appliance remains connected to the live wire even after the fuse has blown, and it can give a shock when touched.

(ii) If a fuse of higher rating than the safe limit of the cables or the appliance is used, it will not blow even if the current exceeds the safe limit and the cables or the appliance may be damaged. This may even cause fire.

(iil) Fuse wires are made from a material of low melting point and low resistance. The resistance, however, depends on the fuse rating (D.21.9).



(a) Conventional fuse



(b) Cartridge fuse

(c) Symbol for fuse

FIG. 21.1 Fuse is a device to protect electrical appliances from damage. (a) A wire of low melting point is connected to two metallic pins embedded in a porcelain base. (b) A cartridge type fuse. The fuse wire is soldered to two metallic plates at the end of a small glass tube. When the fuse blows, the cartridge is simply changed.

(iv) The thickness of the fuse wire depends on its current rating. A thin wire has a low current rating.

D.21.9 Fuse Rating The maximum current which can pass through a fuse wire.

TYPE OF QUANTITY Scalar

WRITTEN REPRESENTATION No fixed symbol.

SPECIFICATION By a number in amperes—5A, 15A, etc.

DOMESTIC ELECTRICAL WIRING

The power cable, having live and neutral wires, from the city electric supply distribution system enters the house at some convenient place. The cable is first connected to a fuse box and then to an electric meter, which measures the consumed electrical energy in kWh. The cables then go to the main switch and finally to the distribution box. From here, one of the two methods of distribution shown in Fig. 21.2 are used.

NOTE The second system is becoming more popular.

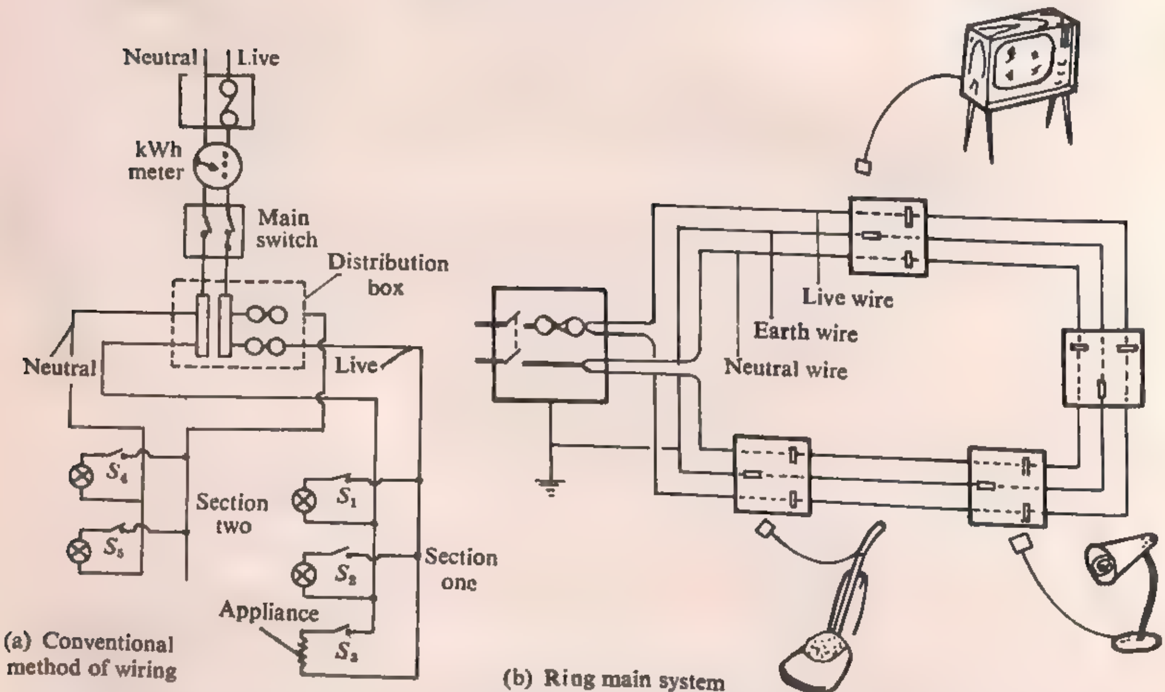


FIG. 21.2 Two methods of domestic wiring. (a) The house for the purpose of supply is divided into more than one section. A cable goes through one whole section and is connected to the distribution box with a fuse of its own. The electrical appliances are connected to this cable in parallel. (b) *Ring main system*. This system is fast replacing method (a). Three cables are laid. Each cable goes round all the rooms and comes back. One cable is connected to the live wire, and another to the neutral wire in the fuse box. The third cable is connected to earth. The appliances with their own fuse are connected to the ring system. In this method an appliance can be connected easily and checked if the fuse blows.

21.3 ELECTRICAL APPLIANCES

In day to day life we use a number of appliances where electrical energy is converted into several other forms of energy. Here we will discuss three types of appliances in which electrical energy is converted either to heat energy, to light energy or mechanical motion.

FIG. 21.3 A filament is a resistance wire in the form of a coil. The wire is wound in the form of a coil because (i) a greater length of the wire can be put in a small space, and (ii) the heat energy produced remains confined to a small area. The energy density is then more and little energy is wasted.

D.21.10 Electrical Appliance An apparatus to convert electrical energy to other useful forms of energy.

EXAMPLES Electric kettle, electric heater, fan, bulb, etc.

D.21.11 Filament A resistance wire in the form of a coil.

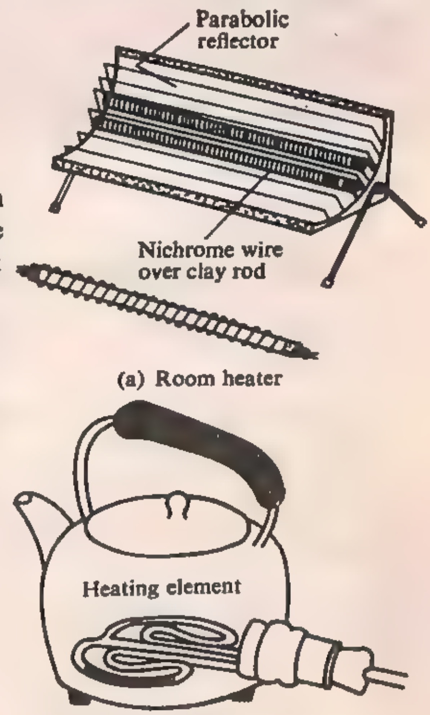
TYPES OF ELECTRICAL APPLIANCES

(*a*) *Appliances which produce heat energy*

WORKING PRINCIPLE When an electric current passes through a resistance wire, the electrons driven by the electric field collide with atoms of the wire, converting electrical energy into heat energy, which is used in several ways.

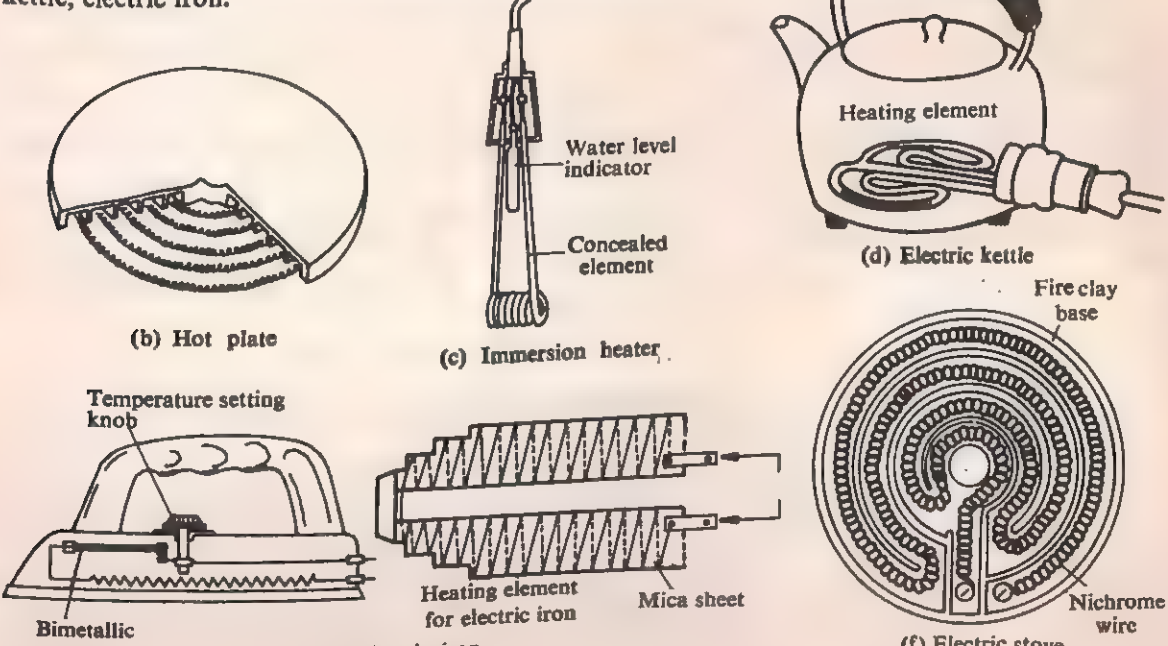
CONSTRUCTION These appliances basically contain a filament of suitable length, an insulating base of fire clay, mica, silica or asbestos and an arrangement for utilising the heat energy.

EXAMPLES Room heater, hot plate, immersion heater, electric kettle, electric iron.



(a) Room heater

(d) Electric kettle



(b) Hot plate

(c) Immersion heater

(e) Electric iron

(f) Electric stove

FIG. 21.4 Some heat producing electrical appliances.

PROPERTIES OF FILAMENT MATERIAL (i) High melting point, (ii) high resistance, (iii) should not react with air at high temperatures.

Nichrome (commonly used in making filament wire) an alloy having 60% nickel and 40% chromium has all these three properties.

NOTE The specific resistance of nichrome is very high.

(*b*) *Appliances which produce light*

WORKING PRINCIPLE At very high temperatures the filament emits light energy besides producing heat energy.

CONSTRUCTION See Fig. 21.5.

EXAMPLE Electric bulb.

NOTES (i) Below a temperature of 600°C most of the electrical energy is converted into heat energy. However, as the temperature increases, more and more electrical energy is converted into light energy.

(ii) The early bulbs used carbon rods placed in vacuum. Their working temperature was about 1300°C but the efficiency was very low.

(iii) In the present day bulbs, the filament is made from tungsten because it has a high melting point. The working temperature is 2500-2700°C. These are much more efficient than the carbon type.

(iv) The use of the coiled coil filament reduces the region around which heat is produced. This way high temperatures can be achieved. These kind of bulbs are even more efficient than the simple tungsten coil bulbs.

(v) The material used for filaments in bulbs must have high melting point.

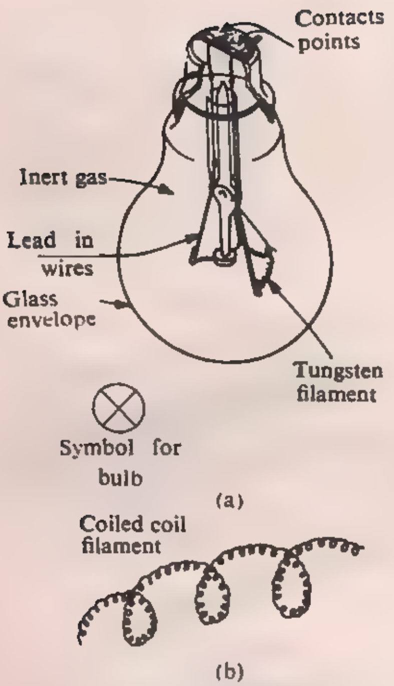


Fig. 21.5 A bulb. A resistance wire in the form of a coiled coil filament made by tungsten is placed inside a thin glass envelope. It is connected to the base by two thick metallic leads of negligible resistance. The inside of the bulb is filled with a mixture of nitrogen and argon, the composition of mixture depends on the wattage of the bulb. Air cannot be used as it will oxidise tungsten. The inert gas prevents the evaporation of the filament metal.

(*c*) *Appliances which produce motion*

WORKING PRINCIPLE These appliances consist of an electric motor fitted with blades. When current passes through the motor the blades start rotating.

EXAMPLE Electric fan, electric mixer.

D.21.12 Earthing The process of connecting the body of an electrical appliance to earth.

IMPORTANCE OF EARTHING If by accident or due to a defect in the insulation, the live wire in an electrical appliance gets connected to the body of the appliance, then the appliance will give a shock to anybody touching it. To prevent this, the body of the appliance is connected to earth through the earth wire. Now, if such a defect occurs, most of the current will go to the earth and no shock will be experienced on touching the appliance.

SOLVED EXAMPLES

(*Note* Wherever necessary take the cost of 1 unit of electricity (1 kWh) as 30 paisa.)

EXAMPLE 21.1 In the rainy season every one of us is aware of lightning flashes. In these flashes tremendous power is delivered. If it were possible to use this power, it would solve all the power requirements of mankind. In a typical flash of lightning the current is 22 000 A and the potential difference between the cloud and ground is as high as 100 million volts. Find the power delivered by such a bolt.

Solution $I = 22\,000$ A and $V = 100$ million volts $= 10^8$ V,

$$P = VI = 10^8 \text{ V} \times 22\,000 \text{ A}$$
$$= 2.2 \times 10^{12} \text{ W}.$$

Answer The power delivered by a lightning bolt is 2.2×10^{12} W.

NOTE It is not possible to use this power because firstly lightning occurs only for a fraction of a second, and secondly we never know where and when it will strike.

EXAMPLE 21.2 In some countries, e.g. in the USA, electricity is supplied at 110 volts instead of 220 volts. In such a country an electric iron is designed to consume 450 W. What is the resistance of the heating coil? How much current will pass through the coil?

Solution $V = 110$ V and $P = 450$ W.

(i) $P = VI$, or

$$I = \frac{P}{V} = \frac{450 \text{ W}}{110 \text{ V}} = 4.09 \text{ A}.$$

(ii) From Ohm's law,

$$R = \frac{V}{I} = \frac{110 \text{ V}}{4.09 \text{ A}} = 26.9\ \Omega$$

Answer The current in the filament is 4.09 A and its resistance is 26.9 Ω.

EXAMPLE 21.3 In the following cases obtain the energy spent in kilowatt hour: (i) a radio of 60 W operating for 50 hours, (ii) a desert cooler of 150 W operating for 150 min, and (iii) a bulb of 40 W lighted for 1800 s.

Solution In solving such problems first convert power of the appliance to kilowatt and time to hours. Then multiply power in kilowatt and time in hours to obtain energy in kilowatt hour.

(i) $P = 60 \text{ W} = 0.060$ kW, and $t = 50$ h.
$E = 0.06 \text{ kW} \times 50 \text{ h} = 3$ kWh.

(ii) $P = 150 \text{ W} = 0.15$ kW, and $t = 150$ min $= 2.5$ h.
$E = 0.15 \text{ kW} \times 2.5 \text{ h} = 0.375$ kWh.

(iii) $P = 40 \text{ W} = 0.04$ kW, and $t = 1800$ s $= 0.5$ h.
$E = 0.04 \text{ kW} \times 0.5 \text{ h} = 0.02$ kWh.

Answer The energy consumed in the three cases is 3 kWh, 0.375 kWh and 0.02 kWh, respectively.

Suggestion Unless asked specifically to calculate in kWh, always calculate energy consumed in Joules. Do this problem again and write the answers in Joules.

EXAMPLE 21.4 In how much time will an electric heater labelled as 250 W generate 3.6×10^6 J of heat?

Solution $P = 250$ W and $E = 3.6 \times 10^6$ J. From the definition of power,

$$P = \frac{E}{t},$$

or

$$t = \frac{E}{P} = \frac{3.6 \times 10^6 \text{ J}}{250 \text{ W}} = 14\,400 \text{ s}$$
$$= 4 \text{ h}.$$

Answer 3.6×10^6 J of heat will be produced in 4 hours.

EXAMPLE 21.5 An electric bulb has a resistance of 625Ω.

(i) What is its wattage if it operates on a 250 V mains?

(ii) How much energy wlll it consume in one hour (a) in Joules and (b) in kWh?

(iii) How much will it cost per week if used 7 hours a day?

Solution $R = 625\Omega$, and $V = 250$ V.

(i) $P = VI = \frac{V^2}{R} = \frac{250 \text{ V} \times 250 \text{ V}}{625\Omega}$

$= 100$ W.

(ii) From the definition of power,

Energy consumed per second $= Ps$

$= 100$ W s $= 100$ J.

Energy consumed per hour

$= 100 \text{ J} \times 60 \times 60 = 3.6 \times 10^5$ J.

(b) $P = 100 \text{ W} = 0.1 \text{ kW}, t = 1$ h

$E = 0.1 \text{ kW} \times 1 \text{ h} = 0.1$ kWh.

(iii) Energy consumed per day (7 h) $= 0.1$ kWh$\times 7$ h

$= 0.7$ kWh.

Energy consumed per week $= 0.7 \text{ kWh} \times 7$

$= 4.9$ kWh.

The cost of 1 kWh is Re 0.30. Hence cost of the energy consumed per week $= 4.9 \text{ kWh} \times$ Re 0.30/kWh $=$ Rs 1.47.

Answer (i) The wattage of the bulb is 100 W. (ii) The energy consumed is 3.6×10^5 J or 0.1 kWh. (iii) The cost of energy consumed per week will be Rs 1.47.

EXAMPLE 21.6 A television set labelled as 60 W is used for 5 hours every day. What will be the monthly (30 days) electricity bill if it costs 30 paisa per unit?

Solution $P = \iota$ W $= 0.06$ kW, and $t = 5$ h.

Energy consumed per day $= 0.06 \text{ kW} \times 5$ h

$= 0.3$ kWh.

Energy consumed per month $= 0.3 \text{ kWh} \times 30$

$= 9$ kWh.

Cost of electricity $= 9 \text{ kWh} \times 0.3 \text{ Rs kWh}^{-1}$

$=$ Rs 2.70.

Answer Using the television 5 h a day for the whole month will cost Rs 2.70.

EXAMPLE 21.7 A torch having three cells uses a bulb marked 4.5 V, 0.3 A. The cost of each cell is Rs 2.60. If the cells last 50 hours, what is the cost of 1 kWh?

Solution $V = 4.5$ V, $I = 0.3$ A and cost of three cells $=$ Rs $2.60 \times 3 =$ Rs 7.80.

$P = VI = 4.5 \text{ V} \times 0.3 \text{ A} = 1.35 \text{ W} = 0.001\,35$ kWh.

Energy consumed in 50 hours $= 0.001\,35 \text{ kW} \times 50$ h

$= 0.0675$ kWh

Cost of 1 kWh $= \frac{\text{Rs } 7.80}{0.0675} =$ Rs 115.56

Answer The cost of 1 kWh is Rs 115.56.

EXAMPLE 21.8 An electric bulb is marked as 60 W 250 V. This bulb is used on 230 V mains supply. Calculate (i) the resistance of the filament, (ii) the current passing through the coil when used at 230 V, and (iii) the new wattage.

Solution $F = 60$ W, $V_0 = 250$ V and $V_n = 230$ V.

(i) $P = V_0 I$, or

$$I = \frac{P}{V_0} = \frac{60 \text{ W}}{250 \text{ V}} = 0.24 \text{ A}.$$

From Ohm's law,

$$R = \frac{V_n}{I} = \frac{250 \text{ V}}{0.24 \text{ A}} = 1041.7\Omega$$

(ii) Now the bulb is operating at 230 V,

$$I = \frac{V_n}{R} = \frac{230 \text{ V}}{1041.7\Omega} = 0.22 \text{ A}.$$

(iii) The new wattage $V_n I = 230 \text{ V} \times 0.22$ A $= 50.6$ W.

Answer The resistance of the filament is 1041.7Ω. When it operates on 230 mains, 0.22 A current will pass through it and the new wattage will be 50.6 W.

NOTE In India upto about 1979 bulbs were designed for 250 V but now these are designed for 230 V. In India the mains voltage is 230 V and not 250 V. A bulb made for 250 V draws

less current than one designed for 230V. If the current is less, the working temperature is lower and more heat energy will be produced, thus reducing the efficiency of the bulb.

EXAMPLE 21.9 One day in a house it was noticed that (i) a tubelight of 40 W in the bedroom was on for 5 hours, (ii) a 60 W bulb in the kitchen was on for 4 hours and (iii) a water heater of 1000 W was used for 1 hour. Calculate the cost of electricity used on this day.

Solution For the tube light: $P = 40\text{W} = 0.04\text{ kW}$, and $t = 5$ h. For the bulb: $P = 60\text{W} = 0.06$ kW, and $t = 4$ h. For the water heater: $P = 1000$ W $= 1$ kW, and $t = 1$ h.

$$\text{Energy consumed by tube} = 0.04\text{ kW}\times 5\text{ h} = 0.20\text{ kWh}$$

$$\text{Energy consumed by bulb} = 0.06\text{ kW}\times 4\text{ h} = 0.24\text{ kWh}$$

$$\text{Energy consumed by heater} = 1\text{ kW}\times 1\text{ h} = 1.00\text{ kWh}$$

Total energy consumed in a day = 1.44 kWh. Since the cost of electricity is Re 0.30 per kWh, the total cost of electricity consumed

$$= 1.44\text{ kWh}\times\text{Re } 0.30\text{ kWh}^{-1}$$
$$= \text{Re } 0.43$$

Answer The cost of electricity consumed is Re 0.43.

EXAMPLE 21.10 Determine the fuse rating of the fuse to be used with (i) an electric iron of 500 W, and (ii) an immersion heater of 1000 W. The main voltage is 250 V.

Solution According to the definition of fuse rating, the fuse rating is the maximum current which can pass through the fuse without melting it. We know that $I = P/V$.

(i) $P = 500$ W, and $V = 250$ V

$$I = \frac{500\text{ W}}{250\text{ V}} = 2\text{ A}.$$

Hence fuse wire of rating more than 2 A will work.

(ii) $P = 1000$ W and $V = 250$ V.

$$I = \frac{1000\text{ W}}{250\text{ V}} = 4\text{ A}.$$

Here fuse wire of rating more than 4 A will work.

Answer The fuse rating in the two cases would be more than 2 A and 4 A respectively.

PROBLEMS

(Take one month = 30 days)

21.1 A hot plate is connected to a 250 volt mains supply. Find the resistance of the hot plate if the current drawn is 10 A.

21.2 In automobiles a spark is used to burn the fuel mixture. The spark is provided by a spark plug which operates at 25 000 V. If the current is 0.001 A, find the power spent by the battery during one spark.

21.3 An electric cloth dryer operates at 240 V and uses a current of 16 A. Calculate the cost of electricity to run it for one hour at the rate of 50 paisa per unit.

21.4 A typical refrigerator at home consumes 330 W operating at 220 V. What is the current passing through the coil of the motor and its resistance ?

21.5 What is the resistance of a 100 W bulb if it is designed for (i) 110 V and (ii) 250 V ?

21.6 A thousand watt electric heater is operated at 220 V. Find the (i) current through the coil and (ii) resistance of the coil.

21.7 An electrical appliance connected to a 220 V mains draws a 5 A current. Find the wattage of the appliance.

21.8 The wattage of an electric kettle which draws a current of 2 A is 250 W. What is the voltage supplied by the mains ?

21.9 The resistance of a certain gadget is 200 Ω. How much power does it consume operating on a 220 V mains?

21.10 A bulb marked as 3 V-0.2 A is used in a two cell torch. If each cell costs Rs 2.75 and lasts for 25 hours, find the cost of 1 kWh.

21.11 Two bulbs are marked (i) 100 W, 220 V and 40 W, 220 V, (ii) 40 W, 220 V and 40 W, 110 V, and (iii) 40 W, 220 V and 20 W, 110 V. What is the ratio of resistance in each case?

21.12 The cost of running an electrical appliance for 10 hours is 60 paisa. What is its wattage?

21.13 A tubelight of 40 W is used daily for 5 hours. How much will be your monthly electricity bill?

21.14 An electric iron of 500 W is designed to operate at 250 V. One day the main supply was 220 V. What will be the new wattage and current drawn by the iron filament?

21.15 A house has 5 bulbs of 60 W each and 2 fans of 50 W each. The bulbs are used for 6 hours and the fans run for 8 hours every day. How many units of electricity will be consumed in 30 days?

21.16 In an office a 500 watt refrigerator works for 5 hours each day and a fan of 40 watts works for 10 hours daily. A tubelight of 40 watts is also used for 5 hours in a day. Determine the electricity bill for a month.

21.17 An electric heater is marked 100 W, 250 V. How much heat energy will it produce in one hour if operated on 220 V mains?

21.18 An appliance of 250 W is used for (i) 1 hour, (ii) 4 hours and (iii) 7 hours. How much energy will it consume in kWh?

21.19 Two appliances consume the same energy. One of them of 750 W operates for 50 min. Determine the power of the other appliance if it operates for (i) 30 min, and (ii) 2 hours.

21.20 Two appliances operating for the same time consume equal amount of energy. What is the ratio of their powers?

21.21 The ratio of energy consumed by two immersion rods A and B is (i) 1, (ii) 2 and (iii) 5. Answer the following questions: (a) What is the wattage of A if A and B operate for the same time and the wattage of B is 40 W? (b) What is the operating time for A in the three cases if their wattages are equal and B operates for 30 min?

21.22 A fan operating for 10 hours consumes 1 unit of electricity. Find the wattage of the fan?

21.23 In how much time will an electric iron of 250 W consume 4 units of electricity?

21.24 A refrigerator of power 150 W consumes 6 units of electricity. Determine the time of its operation.

21.25 Find the energy consumed in kWh in the following cases (i) bulb of 100 W operates for 15 min, (ii) a TV of 60 W for 3.5 hours and (iii) an electric iron of 450 W for 40 min.

21.26 What will be the maximum current which can be passed through a fuse wire of following rating without melting it: (i) 5 A, (ii) 10 A and (iii) 15 A?

21.27 Determine the power of appliances which can be used on 250 V mains with fuse rating of (i) 1 A, (ii) 4A and (iii) 5A.

21.28 What should be the fuse rating for (i) 10 bulbs of 100 W, (ii) immersion heater of 2000 W + a TV of 60 W+an electric iron of 250 W. Main voltage is 250 V.

21.29 Will an appliance of (i) 1500 W with fuse rating 3 A, (ii) 1000 W with fuse rating 7 A and (iii) 5000 W with fuse rating 10 A work on 220 V mains?

21.30 The safe current carrying capacity of a particular pair of cables is 5 A. An electric motor of 2000 W with a fuse of rating 8 A is used on this line of voltage 250 V. Will it be safe to run the motor? Explain.

Miscellaneous Problems

Chapter 11 STRUCTURE OF MATTER

Q. 11.1 What is matter? Does it have a structure?
Q. 11.2 What are the basic building blocks of matter?
Q. 11.3 What is meant by (i) electron, (ii) proton, (iii) neutron, (iv) nucleus and (v) atomic number?
Q. 11.4 How is an atom formed? Discuss its structure.
Q. 11.5 What is a molecule? How is it formed?
Q. 11.6 Can a molecule be formed by two similar atoms? Give examples.
Q. 11.7 What is an element? Is an element formed by atoms or molecules? Give examples of elements which occur in nature as molecules.
Q. 11.8 What is a compound? Is a compound formed by the combination of similar atoms or dissimilar atoms?
Q. 11.9 Name the forces which are responsible for the formation of nucleus, atoms and molecules.
Q. 11.10 Name a phenomenon which implies existence of atoms and molecules.
Q. 11.11 Explain the terms interatomic force, force of cohesion and force of adhesion.
Q. 11.12 Is force of adhesion greater than force of cohesion? Justify your answer.
Q. 11.13 What is a solid? How many types of solids are possible?
Q. 11.14 What is meant by crystalline solid and amorhous solid? What is the main difference between them? Give two examples of each kind.
Q. 11.15 Explain with examples how the atoms are arranged in a crystalline solid.
Q. 11.16 What are the three states of matter? What is the main difference between them?
Q. 11.17 Discuss briefly conversion of solid to liquid and liquid to gas.
Q. 11.18 What is Brownian motion? What will happen if the size of the particles is increased?
Q. 11.19 Give one example to show that attractive forces exist between molecules of a liquid.
Q. 11.20 What is meant by elasticity and plasticity? Give two examples of elastic and plastic bodies.
Q. 11.21 Why is steel considered to be more elastic than rubber?
Q. 11.22 What is stress, strain and elastic limit? Give their SI units.
Q. 11.23 How is stress related to the restoring force?
Q. 11.24 Explain the restoring force on the basis of molecular structure of the force.
Q. 11.25 Will a solid regain its shape and size if the deforming stress is greater then the elastic limit?
Q. 11.26 What is the shape of the graph between applied force and change in length of the wire if the elastic limit is not crossed?
Q. 11,27 State Hooke's law.
Q. 11.28 What is Young's modulus? What are its units? Describe an experiment to determine it in the laboratory?

Chapter 12 TEMPERATURE AND VOLUME CHANGES

Q. 12.1 Give examples to justify that heat is a form of energy.
Q. 12.2 Give at least one difference between heat energy and other forms of energy.
Q. 12.3 What is the nature of heat? Justify your answer.

Q. 12.4 Name three sources of heat energy. What is the original form of energy in these sources before conversion?

Q. 12.5 What does temperature measure?

Q. 12.6 What is the difference between heat energy and mechanical energy?

Q. 12.7 What is the difference between heat energy and temperature?

Q. 12.8 What happens to the kinetic energy of the molecules of a solid when it is heated?

Q. 12.9 In which direction will the heat energy flow if (i) body A has more heat energy than body B but both of them are at the same temperature? (ii) both the bodies A and B have the same amount of heat energy but A is at a higher temperature?

Q. 12.10 In what respect does the Celsius and Kelvin temperature scales differ?

Q. 12.11 What are the main differences between Fahrenheit and Celsius scales?

Q. 12.12 How do the two thermometers, one marked in degrees and the other in half degrees differ from each other?

Q. 12.13 Explain why melting ice and not solid ice should be used in checking the lower fixed point?

Q. 12.14 What are ice and steam points?

Q. 12.15 What is the fundamental interval of Celsius, Fahrenheit and Kelvin scales?

Q. 12.16 Give one advantage and one disadvantage each of using alcohol, mercury and water as thermometer liquids.

Q. 12.17 Give four properties of a liquid suitable for thermometers.

Q. 12.18 Name three properties which could be used in the measurement of temperature.

Q. 12.19 Two thermometers are constructed from capillary tubes of different bore diameters. Which one will be more accurate? Why?

Q. 12.20 Explain : (i) When the brakes of a moving car are applied for a considerable time, they get hot. (ii) When air is pumped into cycle tyres, the pump gets warm. (iii) The temperature of the water at the bottom of a fall is slightly higher than the temperature at the top. (iv) When we rub our hands for some time, they become warm.

Q. 12.21 How can you increase the accuracy of a thermometer?

Q. 12.22 Explain briefly why in a clinical thermometer (i) the bulb is small, (ii) the bulb is a long cylinder and is not spherical, (iii) there is a constriction, and (iv) it is marked only between 36 °C and 42 °C?

Q. 12.23 Describe briefly how you would construct a thermometer?

Q. 12.24 Glass thermometers are filled with either mercury or alcohol. Which of these is more effective in measuring very low temperatures?

Q. 12.25 In polar regions, clinical thermometers use alcohol. Why?

Q. 12.26 Explain why in a maximum thermometer the indicators do not move with the level of mercury?

Q. 12.27 Discuss in terms of internal molecular motion, the expansion of solids, liquids and gases on heating.

Q. 12.28 Why do solids expand when heated?

Q. 12.29 What do you understand by the statement that the coefficient of linear expansion of copper is 17×10^{-6} °C^{-1}?

Q. 12.30 Does the magnitude of coefficient of linear expansion depend on the temperature scale?

Q. 12.31 Name three instruments based on the expansion of solids.

Q. 12.32 Give some disadvantages of thermal expansion.

Q. 12.33 Explain the working of the bimetallic strip in a thermostat.

Q. 12.34 Why does a bimetallic strip bend on heating?

Q. 12.35 Explain why : (i) a gap is left between two steel rails, (ii) the end of bridges are placed on rollers, (iii) an iron rim is heated before it is placed on a wagon wheel, (iv) a thick glass tumbler is likely to break when hot liquid is poured into it?

Q. 12.36 A solid plate has a circular hole in it. Will the hole expand or contract on heating the plate?

Q. 12.37 Establish a relation between (i) coefficient of linear expansion and superficial expansion and (iii) coefficient of linear expansion and cubic expansion.

Q. 12.38 What do you understand by coefficient of linear, superficial and cubic expansion?

Q. 12.39 Can you define coefficient of linear expansion for gases?

Q. 12.40 When a mercury thermometer is thrust into boiling water, the mercury first falls and then rises. Why?

Q. 12.41 In what respect does the expansion of water differ from that of other liquids?

Q. 12.42 Why is anamolous expansion of water essential for the survival of marine life?

Q. 12.43 What temperature do you expect at the bottom of a lake which has ice on its surface?

Q. 12.44 What is apparent expansion? Why is there a need to define it?

Q. 12.45 Explain the difference between real and apparent expansion of liquids.

Q. 12.46 State the law which gives a relation between (i) pressure and temperature of a gas at constant volume and (ii) temperature and volume of a gas at constant pressure?

Q. 12.47 What is the normal temperature of human body on the Kelvin scale?

Q. 12.48 Which expands more on heating—a gas or a liquid?

Q. 12.49 On the basis of expansion of gases show that temperature cannot go below −273°C.

Q. 12.50 When a metal bar is heated, do the following increase, decrease or remain unchanged : (i) length, (ii) volume, (iii) density, (iv) mass?

Q. 12.51 Which expands more on heating, alcohol or mercury?

Chapter 13 MEASUREMENT OF HEAT ENERGY

Q. 13.1 What is the unit of heat energy?

Q. 13.2 What is a calorie? What does it measure?

Q. 13.3 What is the relation between calorie and the corresponding SI unit?

Q. 13.4 Define the term specific heat capacity. What are its units?

Q. 13.5 What is the difference between the terms specific heat capacity and heat capacity?

Q. 13.6 Does the flow of heat energy from one object to another depend on their specific heat capacities or on their temperature?

Q. 13.7 Write down the expression of heat gained by a body when its temperature changes from T_1 to T_2.

Q. 13.8 Explain the change of state on the basis of internal structure of matter.

Q. 13.9 Which substance has the highest specific heat capacity?

Q. 13.10 Explain why water is preferred in a car radiator to cool the engine.

Q. 13.11 Discuss briefly two important applications of the high specific heat capacity of water.

Q. 13.12 Why does the atmospheric temperature not change much near the sea?

Q. 13.13 Sometimes farmers fill their fields with water in the night to save their crops from frost. Why?

Q. 13.14 What is meant by latent heat? Why is it called latent?

Q. 13.15 Explain the origin of latent heat of fusion on the basis of internal structure of matter.

Q. 13.16 What is the difference between specific heat capacity and specific latent heat of steam?

Q. 13.17 Explain why a steam burn is more serious than a hot water burn at the same temperature.

Q. 13.18 What happens to the supplied heat energy when water boils at constant temperature?

Q. 13.19 Is it possible to add heat to a substance without changing its temperature? Explain.

Q. 13.20 What is the principle of a calorimeter?

Q. 13.21 With the help of a neat diagram, explain how you will determine the specific heat capacity of (i) a liquid, and (ii) a solid?

Q. 13.22 In some calorimeter experiments solids are heated in steam and not in boiling water. Why?

Q. 13.23 What are the sources of error in calorimeter experiments?

Q. 13.24 Why is ice thoroughly dried while determining its specific latent heat of fusion?

Q. 13.25 On hills it is cooler when ice melts than during snowfall. Why?

Q. 13.26 When water freezes, is heat transferred to the water or away from the water? Give an example where this heat transfer is important.

Q. 13.27 When ice melts, is heat transferred to the ice of away from it? Give an example where this heat transfer is important.

Q. 13.28 What is meant by calorific value of fuels?

Q. 13.29 What is a bomb calorimeter? How is it different from an ordinary calorimeter?

Q. 13.30 A perspiring person feels cool in front of a running fan even though the air blown by the fan is at atmospheric temperature. Why?

Q. 13.31 How many joules of mechanical work produce 1 calorie of heat?

Chapter 14 REFLECTION OF LIGHT

Q. 14.1 What is the nature of light? Give two phenomena in support of your answer.

Q. 14.2 What is the difference between a ray of light and a beam of light?

Q. 14.3 How many types of beams of light do you know? Explain with the help of a neat diagram.

Q. 14.4 What is the main difference between (i) parallel and divergent beams of light and (ii) divergent and convergent beams of light?

Q. 14.5 What do you understand by the phenomenon of reflection? Why is it so important?

Q. 14.6 When sunlight falls on a wall we see the wall but when it falls on a plane mirror we see the sun. Why?

Q. 14.7 Which phenomenon helps you to see a non-luminous object? How?

Q. 14.8 Define the terms (i) angle of reflection, (ii) angle of incidence, (iii) regular reflection, (iv) diffuse reflection, (v) normal incidence, and (vi) grazing incidence.

Q. 14.9 State the laws of reflection.

Q. 14.10 Is angle of reflection always equal to the angle of incidence?

Q. 14.11 How will you demonstrate experimentally that the angle of incidence equals the angle of reflection?

Q. 14.12 What is the name of the angle between a ray falling on a plane mirror and the normal to the plane mirror?

Q. 14.13 A ray of light falls on a plane mirror along the normal. In which direction will it go after reflection?

Q. 14.14 What should be the angle of incidence if (i) reflected ray is in the same direction as the incident ray, (ii) reflected ray is in opposite direction to the incident ray?

Q. 14.15 A beam of parallel light falls on a smooth surface and on an uneven surface. How does the reflected ray differ in the two cases?

Q. 14.16 What is a plane mirror?

Q. 14.17 Why is the reflecting material not generally deposited on the front surface of a plane mirror?

Q. 14.18 Are laws of reflection valid for diffused reflection?

Q. 14.19 How would you find experimentally the position of the image of a pin placed in front of a plane mirror?

Q. 14.20 Discuss the characteristics of the image formed by a plane mirror.

Q. 14.21 What effect do the following have on the image formed by a plane mirror: (i) size of the plane mirror, and (ii) distance of the object from the mirror?

Q. 14.22 What should be the minimum size of the mirror to enable a person to see his full figure. Prove your answer. Does the object distance change the answer?

Q. 14.23 Give at least two differences between real and virtual images.

Q. 14.24 Can you photograph an image formed by a plane mirror?

Q. 14.25 Is it possible for a plane mirror to form a real image? Explain.

Q. 14.26 A real image is formed by a plane mirror. Is the beam falling on the mirror convergent or divergent?

Q. 14.27 Prove that (i) the images formed by a plane mirror is of the same size as the object, and (ii) the images and the object are at the same distance on either side of the mirror.

Q. 14.28 Explain briefly the meaning of lateral inversion.

Q. 14.29 What is the angle of reflection when the incident ray of light travels along the normal to the mirror?

Chapter 15 REFLECTION AT CURVED SURFACES

Q. 15.1 What is a spherical mirror?

Q. 15.2 Are laws of reflection valid for curved mirrors?

Q. 15.3 In what respects is a spherical mirror different as compared to a plane mirror?

Q. 15.4 A curved glass plate is given to you. Explain in not more than eight sentences how you will convert it into (i) concave mirror and (ii) convex mirror?

Q. 15.5 Give one difference between concave and convex mirrors. How can you distinguish between them simply by touching.

Q. 15.6 Name some applications where spherical mirrors are used.

Q. 15.7 Define the terms pole, focus, radius of curvature, principal axis, focal length and magnification.

Q. 15.8 Can the focus of a convex mirror be obtained on a screen?

Q. 15.9 Why does a ray passing through the centre of curvature, after reflection, retrace its own path?

Q. 15.10 From which point of the principal axis should a ray pass if it is to remain undeviated?

Q. 15.11 Which of the following mirrors can produce a convergent beam: (i) plane, (ii) convex or (iii) concave?

Q. 15.12 A parallel beam of light falls on (i) concave, (ii) convex mirror. What is the nature of the reflected beam in each case?

Q. 15.13 In which mirror do the rays after reflection always become divergent?

Q. 15.14 Should a shaving mirror be concave or convex?

Q. 15.15 What is the radius of curvature of a plane mirror?

Q. 15.16 Suppose you are given a sharp needle. Explain how you would determine the centre of curvature of a concave mirror?

Q. 15.17 Give one practical application of the concave mirror in which a real image is used and one in which a virtual image is used.

Q. 15.18 Suppose someone wants to mount a mirror at the edge of a blind curve to enable the traffic on the other side to be seen. What advice will

you give him about the nature of the mirror to be used?

Q. 15.19 Name the mirror in which a parallel incident beam of light after reflection remains parallel.

Q. 15.20 An object is brought from infinity to very close to a concave mirror. Discuss how the nature and the size of the image varies.

Q. 15.21 Name the three special rays which are used in the construction of the image by a spherical mirror?

Q. 15.22 With the help of a neat diagram find the position of the image when the object is (i) beyond radius of curvature, (ii) between focus and radius of curvature, and (iii) at the radius of curvature. The mirror is concave.

Q. 15.23 Derive the mirror formula.

Q. 15.24 What is the relation between object distance, image distance and focal length?

Q. 15.25 Give one advantage of using convex mirror as rear-view mirror in vehicles.

Q. 15.26 Show that the focal length of a spherical mirror is half of the radius of curvature.

Q. 15.27 What is the position of the object if the image is (i) of same size, (ii) never formed and (iii) a point. The mirror is concave.

Q. 15.28 What is the relation between object distance, image distance and magnification?

Q. 15.29 Explain how you will locate geometrically the image of an object as formed by (i) concave and (ii) convex mirror?

Q. 15.30 Discuss with the help of the mirror formula the position of the image when the object is (i) at infinity, (ii) at the centre of curvature (iii) between C and F, and (iv) at the focus.

Q. 15.31 In which mirror is the magnification (i) always one, (ii) always less than one, and (iii) varies with the position of the object?

Q. 15.32 Explain the sign convention used for formation of images by lenses and mirrors.

Q. 15.33 One wants to see an enlarged image of an object in a mirror. What type of mirror should one use?

Q. 15.34 Where should an object be placed in front of a concave mirror so as to obtain its magnified erect image?

Q. 15.35 Conventionally, is the focal length of a concave mirror taken to be negative or positive?

Q. 15.36 What is spherical aberration? In which kind of mirror it is absent?

Q. 15.37 How would you distinguish without touching whether a given mirror is plane, concave or convex?

Q. 15.38 Why is the image formed by a concave mirror of an object at infinity not a point?

Q. 15.39 What are parabolic mirrors? Where are they used?

Q. 15.40 In which respect is a parabolic mirror better than a spherical mirror?

Q. 15.41 An object of very small size is placed at the focus of a concave mirror. The reflected beam of light is not a parallel beam. Why?

Q. 15.42 Draw an object-image concave mirror ray diagram such that (i) both object and image distances are negative (ii) object distance is negative while image distance is positive.

Chapter 16 REFRACTION AND LENSES

Q. 16.1 What is a lens?

Q. 16.2 Can both the surfaces of a lens be plain?

Q. 16.3 Name the phenomenon on which the working of the lens depends.

Q. 16.4 Draw and name the three kinds of (i) converging lenses, and (ii) diverging lenses.

Q. 16.5 Define the following terms: centre of curvature, principal axis, optical centre, principal section, radius of curvature, primary and secondary focus, focal length.

Q. 16.6 Why does a lens have two focal points and mirror only one?

Q. 16.7 Can the two radii of curvature of a lens be different?

Q. 16.8 What do you understand by converging and diverging lenses?

Q. 16.9 What is the main difference between a lens and a curved mirror?

Q. 16.10 Why is a converging lens sometimes known as a positive lens?

Q. 16.11 Why is a concave lens called a diverging lens?

Q. 16.12 It is said that in action a spherical lens is similar to a set of prisms. Discuss the validity of this statement.

Q. 16.13 Which lens always produces a virtual image?

Q. 16.14 What is meant by a thin lens?

Q. 16.15 Derive the lens formula.

Q. 16.16 What is the power of a lens?

Q. 16.17 With the help of the lens formula explain where the image will be formed if (i) object is at infinity, (ii) object is at focus, and (iii) object is between pole and focus.

Q. 16.18 Write down the formula for a lens connecting image distance, object distance and the focal length. Explain the sign convention you have used.

Q. 16.19 Define the term dioptre.

Q. 16.20 The power of a lens is 2 dioptre. What do you understand by this statement?

Q. 16.21 Name the three important rays used for construction of images. Explain how the image is located?

Q. 16.22 An object is brought from a great distance to near the lens. Discuss the position and nature of the image if the lens is (i) concave and (ii) convex. Draw a neat diagram in each case.

Q. 16.23 A lens is capable of giving an image of the same size as that of the object. What kind of lens is it?

Q. 16.24 Name the position of objects for which (i) image is of same size, (ii) image is not formed, and (iii) image is a point.

Q. 16.25 How will you distinguish between a glass slab, concave lens and convex lens (i) by touching and (ii) without touching.

Q. 16.26 When a lens is used to magnify an object, the object is not really made larger? What does the lens really do?

Q. 16.27 If the image formed by a lens is always diminished and erect, what is the nature of the lens?

Chapter 17 OPTICAL INSTRUMENTS

Q. 17.1 What is an optical instrument? How is it useful to us?

Q. 17.2 The eye is an optical instrument. Justify this statement.

Q. 17.3 Draw a labelled diagram of the eye.

Q. 17.4 How does the eye adjust to permit it to function under conditions of radically different light conditions?

Q. 17.5 How does the eye change the power of the lens?

Q. 17.6 What is a reduced eye? Explain with the help of a neat diagram.

Q. 17.7 Which part in the eye deviates the light most?

Q. 17.8 What is accomodation? How does the eye achieve it?

Q. 17.9 Explain the meaning of normal vision.

Q. 17.10 What is the distance of (i) far point and (ii) near point of a normal eye?

Q. 17.11 What do you understand by the persistence of vision? How it is useful?

Q. 17.12 Name four defects of the eye. Discuss in brief their causes.

Q. 17.13 Where is the near point and far point in (i) myopic and (ii) hypermetropic eye?

Q. 17.14 Name the kind of lens which you will use to remove (i) myopia, (ii) astigmatism, (iii) hypermetropia from the eye.

Q. 17.15 In which kind of defect does the eye ball become (i) elongated, (ii)oblong?

Q. 17.16 Name the defect of the eye if a person is using spectacles with convex lenses.

Q. 17.17 In a myopic eye where will a parallel beam of light be focussed?

Q. 17.18 In a hypermetropic eye where will the image of a nearby object be formed?

Q. 17.19 Name that part of the eye (i) where light does not produce any visual sensation, and (ii) which is most sensitive to light.

Q. 17.20 Draw a diagram of the eye and mark on it optic axis and visual axis. What is the difference between them?

Q. 17.21 What is a camera? What does it do?

Q. 17.22 Explain as briefly as possible with the help of a neat diagram the various parts of a camera.

Q. 17.23 How is the camera similar to the eye? In what respects does it differ?

Q. 17.24 Explain the terms (i) depth of field, (ii) shutter speed, (iii) exposure time, and (iv) *f*-number.

Q. 17.25 On what factor does the size of the image on the film in a camera depend?

Q. 17.26 Where are the object and image in a camera situated with respect to the lens?

Q. 17.27 How does the (i) eye and (ii) camera accomodate objects which are at different distances?

Q. 17.28 How much more light will pass through the shutter of a camera if the *f*-number is increased by one step?

Q. 17.29 What does *f*-number represent in a camera?

Q. 17.30 Is a lens with *f*/5.6 faster or slower than one with *f*/16? (Faster means that a given object is photographed with a shorter exposure time.)

Q. 17.31 A camera has *f*-numbers 2.8 and 22. Which of these two would you select in order to minimize the light falling on the film?

Q. 17.32 Which of the two *f*-numbers of Q. 17.31 would you select on a (i) very bright day and (ii) cloudy day?

Q. 17.33 Which of two *f*-numbers of Q. 17.31 will give greater depth of field?

Q. 17.34 Can there be an optical instrument with only one lens?

Q. 17.35 What is meant by objective and eyepiece?

Q. 17.36 What is the difference between an eyepiece and an objective lens?

Q. 17.37 Name the lens system near the (i) eye and (ii) object in an optical instrument.

Q. 17.38 What is a microscope? What is its main function?

Q. 17.39 Explain with the help of a diagram the working of a simple microscope.

Q. 17.40 Can you construct a simple microscope from a concave lens?

Q. 17.41 What is the distance between image and eye in a simple microscope?

Q. 17.42 Can the image in a simple microscope be obtained on the screen?

Q. 17.43 What is a compound microscope? Give two differences between a simple and a compound microscope.

Q. 17.44 Describe with the help of a diagram, how you would set up two suitable lenses to form a compound microscope.

Q. 17.45 What is the position of object with respect to the objective in (i) microscope, and (ii) telescope?

Q. 17.46 Which image, intermediate or final, is virtual in a (i) compound microscope (ii) telescope?

Q. 17.47 With the help of a diagram explain the working of a compound microscope.

Q. 17.48 Which of the two lenses in a (i) compound microscope, (ii) telescope, has greater focal length?

Q. 17.49 Name the optical instrument used to view (i) nearby objects, (ii) far away objects and (iii) far away objects with the image being real and upright.

Q. 17.50 What is the main difference between (i) astronomical and terrestrial, (ii) Galilean and astronomical, and (iii) refracting and reflecting telescopes?

Q. 17.51 Why does the objective of a telescope have a large diameter?

Q. 17.52 Which has a larger diameter, the objective of the telescope or the microscope?

Q. 17.53 Why is magnification defined differently in telescopes than in mirrors and lenses?

Q. 17.54 Name two differences between a telescope and microscope?

Q. 17.55 How would you distinguish between a microscope and telescope simply by looking at them?

Q. 17.56 Where is the final image formed in (i) simple microscope, (ii) compound microscope, (iii) Galilean telescope, (iv) camera, and (v) eye?

Q. 17.57 Suppose you have three converging lenses of focal length 1 m, 20 cm, and 0.5 cm. Which would you use as (a) the objective of a compound microscope, (b) eye piece of a compound microscope, and (c) the objective of a telescope?

Q. 17.58 Name the type of lens used as (i) magnifier (ii) eye piece of a Galilean telescope, (iii) to correct myopia and presbiopia and (iv) in a camera.

Q. 17.59 Which of the following form a real image: eye, camera, microscope, Galilean telescope, plane mirror, concave shaving mirror?

Q. 17.60 Draw a labelled diagram of a projector.

Q. 17.61 Explain the function of the following parts in a projector: reflector, condenser, filter, slide frame, projecting lens.

Q. 17.62 How is a sharp image projected on the screen by a projector?

Q. 17.63 What is the difference between a projector and a camera?

Q. 17.64 Why is the slide kept upside down in the slide frame of a projector?

Q. 17.65 Name the optical instrument which is opposite to the camera in action.

Q. 17.66 List the optical instruments which form (i) magnified and (ii) reduced image of an object.

Chapter 18 ELECTROSTATICS, CURRENT AND POTENTIAL DIFFERENCE

Q. 18.1 What do you understand by the terms electrostatics and electric charge?

Q. 18.2 What is the minimum possible magnitude of the electric charge?

Q. 18.3 Give two methods to produce electric charges.

Q. 18.4 How many kinds of electric charges exist in nature?

Q. 18.5 A charged body is given to you. How will you determine the sign of its charge?

Q. 18.6 When two bodies attract or repel each other electrically, must both of them be charged?

Q. 18.7 When two bodies *A* and *B* are rubbed together, some electrons go from *A* to *B*. What will be the sign of the charge on body *A*?

Q. 18.8 State the law which gives the magnitude of the force between two charged bodies.

Q. 18.9 What is the direction of the force between two charged bodies?

Q. 18.10 When is force between charges attractive and when is it repulsive?

Q. 18.11 What is the SI unit of charge? How is it defined?

Q. 18.12 Define the terms electric field and electric field strength.

Q. 18.13 Can an electric field exist without an electric charge?

Q. 18.14 Does the definition of electric field depend on the magnitude of charge or on its sign?

Q. 18.15 Does electric field strength have a sign?

Q. 18.16 On what factors does electric field strength depend?

Q. 18.17 What is meant by uniform electric field? Give one situation where it is produced?

Q. 18.18 In what respect do potential and potential difference differ from each other?

Q. 18.19 When is the potential negative? When is it positive?

Q. 18.20 A positive charge moves from point *A* to point *B*. Which point is at a higher potential?

Q. 18.21 In Q.18.20 if the charge is negative what will be your answer?

Q. 18.22 A positively charged plate is connected to ground. In which direction will the positive charge move?

Q. 18.23 Define the following terms: electric current, potential, potential difference, resistance, equivalent resistance, electric charge, electric field strength, electric field and resistivity.

Q. 18.24 Write the SI units of quantities given in Q.18.23.

Q. 18.25 Answer Q.18.22 if the plate is negatively charged.

Q. 18.26 Classify the quantities of Q.18.23 either as vector or scalar.

Q. 18.27 Do electrons flow from high to low potential or from low to high potential?

Q. 18.28 What is the direction of current inside a dry cell?

Q. 18.29 When a current flows inside a metallic wire, what is it that actually moves?

Q. 18.30 In a conductor electrons are moving from end *A* to end *B*. What is the direction of electric current?

Q. 18.31 How is the conventional direction of current defined?

Q. 18.32 Which particle constitutes an electric current in a metallic conductor?

Q. 18.33 Current is never used up in a resistor; the amount of current flowing out of a resistor is the same as that flowing into it. Explain this statement?

Q. 18.34 What is meant by good conductor and bad conductor? Give at least one difference between them?

Q. 18.35 Name some good conductors and bad conductors of electricity.

Q. 18.36 Distinguish between resistance and resistivity of a wire.

Q. 18.37 On what factors does the resistance of a wire depend?

Q. 18.38 State Ohm's law. How can it be used to define resistance?

Q. 18.39 State the condition for which Ohm's law is not valid.

Q. 18.40 Discuss briefly how you would verify Ohm's law in the laboratory?

Q. 18.41 Give one example of a current carrying device where Ohm's law is not valid.

Q. 18.42 For a device, the graph between current and potential difference is not a straight line. Is Ohm's law valid for such a device?

Q. 18.43 Show that the product VI has the dimensions of power. Show that Vm and NC^{-1} have the same dimensions.

Q. 18.44 What is the relation between potential difference and electric field intensity?

Q. 18.45 Name some sources of electric current.

Q. 18.46 Find the expression of equivalent resistance when three resistances are joined in parallel or series.

Q. 18.47 When is a combination of resistances called a series combination, and when is it called a parallel combination?

Q. 18.48 Give at least one important difference between parallel and series combination of resistances.

Q. 18.49 Two resistances are connected such that the total resistance is (i) more, (ii) less than the individual resistance. Are they connected in series or parallel?

Q. 18.50 In which kind of combination of resistances does the same current pass through all the resistances? In this combination which quantity varies from resistor to resistor?

Q. 18.51 In which kind of combination of resistances does different current pass through different resistances? Which quantity is the same for all the resistances?

Q. 18.52 Name a part of an electrical circuit which is heated up when electrical current passes through it.

Q. 18.53 Why does a wire obstruct the flow of current?

Q 18.54 What is EMF? How does it differ from potential difference between two terminals?

Q. 18.55 When is the EMF equal to the potential difference? When are they different?

Q. 18.56 An electron leaves the negative terminal of a cell and reaches the positive terminal after passing through the circuit. In which respect does the electron at the negative terminal differ from that at the positive terminal?

Chapter 19 MAGNETIC EFFECTS OF CURRENTS

Q. 19.1 What do you understand by the term magnetism?

Q. 19.2 How will you demonstrate that a given piece of material is a magnet?

Q. 19.3 Can a stationary charge produce magnetic effect?

Q. 19.4 Suppose we take a permanent magnet on moon. Will it retain its magnetism?

Q 19.5 Define the following terms: pole, magnetic field, neutral points and magnetic lines of force.

Q. 19.6 State some properties of magnetic lines of force.

Q. 19.7 Why cannot two magnetic lines of force cross each other?

Q. 19.8 Sketch magnetic field around a bar magnet when (i) earth's magnetic field is present, (ii) it is absent.

Q. 19.9 Suppose you are given a diagram with magnetic lines of force drawn on it. Explain how you will find the direction of the magnetic force on a unit north pole placed at any point.

Q. 19.10 Why should a magnetic field have at least two neutral points?

Q. 19.11 What is the reason of existence of neutral points in a single bar magnet?

Q. 19.12 Suppose a magnetic needle is placed on a neutral point. In which direction will it point?

Q. 19.13 Describe with the help of a diagram, how you will plot magnetic field of a bar magnet.

Q. 19.14 What is the Oersted's experiment? What did it demonstrate?

Q. 19.15 How will you demonstrate that a magnetic field is associated with an electric field?

Q. 19.16 Sketch the magnetic field around a (i) long current carrying wire and (ii) circular coil.

Q. 19.17 Name and state two rules which could be used to determine the direction of the magnetic lines of force associated with a straight current carrying wire.

Q. 19.18 What is a solenoid? In which respect is it similar to a simple bar magnet?

Q. 19.19 A solenoid is free to rotate in a horizontal plane. In which direction will its ends point?

Q. 19.20 Give a method of determining the N and S poles of a solenoid.

Q. 19.21 How can an electromagnet be produced? Name some applications of it.

Q. 19.22 In a horse shoe electromagnet the electric current in two arms is opposite to each other. What will happen if the current in two arms is in the same direction?

Q. 19.23 Name the material which is normally used as the core in electromagnets.

Q. 19.24 What should be the properties of the core material in electromagnets?

Q. 19.25 Describe with the help of a neat labelled diagram the construction and working of (i) electric bell, (ii) microphone, (iii) earphone.

Q. 19.26 Why can a permanent magnet not be used in an electric bell?

Q. 19.27 How is a variable current produced in a carbon microphone?

Q. 19.28 Give the main difference between electric bell and microphone, electric bell and earphone.

Q. 19.29 Two current carrying wires are placed close to each other. When will they attract each other? When will they repel each other?

Q. 19.30 State and name the rule which gives the direction of force acting upon a current carrying conductor placed in a magnetic field.

Q. 19.31 An electron passing through an apparatus is undeflected. Does this imply that the apparatus has no magnetic field?

Q. 19.32 Describe how the force between two current carrying wires can be used to define unit of ampere?

Q. 19.33 State the condition when the force on a current carrying wire placed in a magnetic field is zero? When is it maximum?

Q. 19.34 On what factors does the strength of the force exerted by a magnetic field on a current carrying wire depend?

Q. 19.35 What is the principle of a galvanometer? What does it measure?

Q. 19.36 How many kinds of galvanometers do you know? Which one is more sensitive?

Q. 19.37 Why should a voltmeter be connected in series and an ammeter in parallel? What will happen if it is done the other way round?

Q. 19.38 Which of the following instruments has least resistance and which one maximum: galvanometer, ammeter, voltmeter?

Q. 19.39 What is an electric motor? What function does it perform? How does it work? Draw a neat labelled diagram of it.

Q. 19.40 In the following instruments name the kind of energy before and after conversion: headphone, electric motor, microphone.

Q. 19.41 Draw a neat diagram of a microphone and explain its working.

Q. 19.42 Describe an experiment to show that magnetic field is associated with an electric current.

Q. 19.43 Repulsion and not attraction is the sure test of magnetism. Justify the statement.

Chapter 20 ELECTRON

Q. 20.1 Explain with the help of a neat diagram the various parts of a discharge tube.

Q. 20.2 Why does no current pass through gases at atmospherc pressure?

Q. 20.3 Approximately at what pressure are the following phenomena observed: positive column, negative glow, Faraday dark space, Crooke's dark space, anode glow?

Q. 20.4 On what factors does the colour of positive column depend?

Q. 20.5 What is the colour of positive column if the gas in the discharge tube is: air, helium, neon, hydrogen?

Q. 20.6 At what pressure does the brightly lit advertising sign boards operate?

Q. 20.7 In a discharge tube why does the glass begin to glow at a pressure of around 0.01 mm Hg.

Q. 20.8 What are cathode rays?

Q. 20.9 Which electrode emits cathode rays?

Q. 20.10 How will you demonstrate that cathode rays (i) are negatively charged particles, (ii) carry energy, and (iii) travel in straight lines?

Q. 20.11 State the four important properties of cathode rays.

Q. 20.12 Does the nature of cathode rays depend on the gas used?

Q. 20.13 Explain the following terms: mobile electrons, work function, thermionic emission, vacuum tube, space charge, rectification, amplification.

Q. 20.14 Name the experiment which demonstrated that for cathode rays, the ratio e/m is constant and independent of the gas.

Q. 20.15 What are the main conclusions of the Thomson experiment?

Q. 20.16 How, in the Thomson experiment, is the spot returned to its original position?

Q. 20.17 In which type of cathode, directly heated or indirectly heated (i) the temperature is more, and (ii) the emission of electrons is more?

Q. 20.18 On what factors does the emission of electrons from a metal depend?

Q. 20.19 Why is energy required to liberate an electron from a metal surface?

Q. 20.20 Name an apparatus which functions on the phenomenon of thermionic emission.

Q. 20.21 What is a diode?

Q. 20.22 Why is a space charge formed in a diode?

Q. 20.23 In which kind of valve, diode or triode, is the space charge more?

Q. 20.24 Should the cathode in diodes be positive or negative for cutting off the plate current?

Q. 20.25 Discuss the use of diode as a half wave rectifier.

Q. 20.26 What is the function of the grid in triodes?

Q. 20.27 What is the difference between a diode and a triode?

Q. 20.28 Draw a circuit diagram to study the mutual characteristics of a triode valve.

Q. 20.29 A signal is to be amplified. In which section, grid, cathode or anode plate, should it be applied?

Q. 20.30 When a triode amplifies a signal the output signal energy is more than the input signal energy. From where does this energy come? Is the law of conservation of energy violated?

Q. 20.31 What is meant by saturation current in a valve? Why does the current not increase after this?

Chapter 21 HOUSEHOLD ELECTRICITY

Q. 21.1 Define the terms watt, watt hour and kilowatt hour.

Q. 21.2 What does watt hour measure, power or energy?

Q. 21.3 What is the difference between kilowatt and kilowatt hour?

Q. 21.4 Name the unit of electricity consumption. Express this unit in SI unit of energy.

Q. 21.5 Name the property of a substance on which energy consumption depends.

Q. 21.6 Explain the difference between live, neutral and earth wire. How will you recognise these in an electrical appliance?

Q. 21.7 Since most household appliances require the same voltage why do these appliances require different currents?

Q. 21.8 What information is needed to calculate the electric power used by an appliance?

Q. 21.9 Which wire is at higher potential, live or neutral?

Q. 21.10 What is a fuse? How does it protect a given appliance from damage?

Q. 21.11 Explain the meaning of fuse rating.

Q. 21.12 When will a fuse blow, at a current greater than the fuse rating or less than it?

Q. 21.13 How is the operation of a fuse related to current?

Q. 21.14 Two fuse wires have different ratings. Both of them are of equal length. What is the difference between them?

Q. 21.15 Which of the following properties should a fuse wire possess: high resistance and high melting point; high resistance and low melting point; low resistance and high melting point; low resistance and low melting point?

Q. 21.16 Two fuse wires of rating 5A and 15A are given.

How will you identify them simply by looking :hem?

Q. 21.17 ιat is the material normally used in fuse wire and in filaments of electrical appliances'

Q. 21.18 Does a filament wire have a high or low resistance?

Q. 21.19 Name electrical appliances which depend (i) on the heating effect of current, (ii) conversion of electrical energy to light energy.

Q. 21.20 In which of the following electrical appliance is the temperature more: (i) electric heater and (ii) electric bulb?

Q. 21.21 Why is the wire in an electric bulb very thin, while the wire in a heater is comparatively thicker?

Q. 21.22 Why should the temperature in an electric bulb be high?

Q. 21.23 What is the function of the inert gas in an electrical bulb?

Q. 21.24 Name one disadvantage of a vacuum bulb.

Q. 21.25 What is the advantage of using coiled coil in bulbs?

Q. 21.26 Draw a neat labelled diagram of the following electrical appliances: heater, electric kettle, electric iron, immersion heater and bulb.

Q. 21.27 What are the main parts of an electrical appaliance based on heating effect of current?

Q. 21.28 What is the shape of reflector in an electrical heater?

Q. 21.29 Discuss the importance of earthing in an electrical appliance. How does it avoid fatal shocks?

Q. 21.30 In a house will you prefer two wire wiring or three wire wiring? Explain.

Q. 21.31 Give two reasons why electrical appliances should be connected in parallel?

Q. 21.32 Why should the fuse and the switches be connected to the live wire and not to the neutral wire?

Q. 21.33 Explain why the filament of a lamp becomes white hot although the connecting leads do not.

Q. 21.34 What will happen if a fuse of higher rating than the desired one is used in the circuit?

Q. 21.35 An appliance originally designed to operate with 7A current with fuse wire of rating 15A is used on a pair of cables designed for 8A. What will happen if due to some fault it suddenly takes a current of 14A?

Q. 21.36 Explain why in electrical bulbs high temperatures are desirable?

Q. 21.37 How is the efficiency of an electrical bulb related to its working temperature?

Answers to Problems

CHAPTER 11

(1) 2 mm (2) 0.05 (3) 62 cm (4) 2 (5) 980 N (6) 5×10^{-5} m^2, (7) 100 N (8) 9.3×10^7 Nm^{-2} (9) 2×10^4 N (10) 0.2 m^2 (11) Side 7 cm (12) 2.9×10^4 N (13) No (14) 5.2×10^{10} Nm^{-2} (15) 7.7×10^{-3} 3 mm (16) 3.2×10^5 N (17) 1.96×10^{-8} m^2 (18) 11×10^{10} Nm^{-2} (19) 1.5×10^{10} Nm^{-2} (20) 1.7×10^{-6} m.

CHAPTER 12

(1) 603 K, 1443 K, 626°F, 2138°F (2) −24.6°C, 160°C (3) 546 K, 409.5 K (4) 68°F, 104°F, 293 K, 313 K (5) −459.4°F (6) 7 cm (7) 20 cm, 0.2 cm, 9.8 cm (8) 50°C (9) 80°C (10) 30.01 cm, 30.016 cm (11) 88.3°C (12) 1.009 cm (13) 40.11 cm (14) 692°C (15) 1.1 m (16) 5×10^{-6} $°C^{-1}$ (17) 6.25×10^{-6} $°C^{-1}$ (18) $(48\ C^{-1}, 38°C^{-1}, 38°C^{-1}, 72°C^{-1}, 57°C^{-1}, 57°C^{-1})\times10^{-6}$ (19) 58823°C (20) 1.0012 cm (21) 17×10^{-6} C^{-1}, 34×10^{-6} $°C^{-1}$ (22) 0.1856 m^2 (23) 1.0043 m^2 (24) 16667°C (25) 5.004 lit, 5.135 lit, 0.131 lit (26) 5.14 cm^3 (27) 1165 kg m^{-3}, 0.515 lit (28) 2.5×10^4 Nm^{-2} (29) 4 (30) 10.8 cc (31) 1.18 lit (32) 4×10^5 Nm^{-2} (33) 16.5%

CHAPTER 13

(1) 4600 $J°C^{-1}$, 17 640 $J°C^{-1}$, 42000 $J°C^{-1}$ (2) 882 J kg^{-1} $°C^{-1}$ (3) 3.96 J (4) 111.4 m (5) 0.23°C (6) 40161°C (7) 347°C (8) 187 500 J, 187.5 J kg^{-1} $°C^{-1}$ (9) 4.85×10^5 J (10) 2100 J kg^{-1} $°C^{-1}$ (11) 700 W (12) 20°C (13) 22.5°C (14) 2.4 kg (15) 250 g (16) 3750 J kg^{-1} $°C^{-1}$ (17) 1.24×10^5 J kg^{-1} (18) 1.05×10^6 J (19) 10 h (20) 798 g (21) 7560 J (22) 3.39×10^6 J (23) 1.19×10^6 J (24) 342×10^3 J kg^{-1} (25) 1.26 kg (26) 3.9 g (27) 10.5 g (28) 1050 J kg^{-1} $°C^{-1}$ (29) 6.8°C (30) 2268×10^3 J kg^{-1} (31) 1880 J $kg^{-1}$$°C^{-1}$ (32) 926°C (33) 6.8×10^6 J kg^{-1}, 1.1×10^6 J kg^{-1} (34) 3.36×10^6 J, 2.26×10^7 J (35) 56.7°C.

CHAPTER 14

(1) 10°, 40°, 0° (2) 10 cm in front (3) 4 cm (4) 5 cm towards the mirror (5) 1.2 m (6) 1 ms^{-1} (7) 4 ms^{-1} (8) 4 ms^{-1} (9) 20°.

CHAPTER 15

(1) 30 cm, 15 cm (2) 20 cm, 40 cm (3) 35 cm (4) Concave mirror of focal length 50 cm (5) 20 cm (6) 20 cm (7) −30 cm, yes (8) 0.84 m in front of the mirror (9) 2, −2 (10) 0.25, −0.25; real, virtual (11) −2 (12) 80 cm in front of mirror; 80 cm behind the mirror (13) 1.2 m in front of mirror, 0.3 m behind the mirror (14) 4 cm high real, 4 cm high virtual (15) 1 cm high (16) Concave, 1.2 m in front of mirror (17) 2 m high, 50.5 m from the mirror (18) 180 cm, −60 cm

(19) −200 cm, −50 cm; −1.2 m, 0.3 m (20) 1.2 m in front of mirror, 0.4 m in front of mirror (21) 15 cm from candle, 11.25 cm (22) 60 cm in front of mirror, real 2 cm high, 2; 12 cm behind the mirror, virtual, 0.4 cm high, −0.4 (23) 75 cm in front of mirror, 5 cm high (24) 60 cm in front of mirror, 6 cm high, (25) 20 cm., real.

CHAPTER 16

(2) 50 cm (3) 5 D, 2.5 D, −10 D, −2 D, −1.3D (4) 30 cm, 2.5 cm, −0.5 (5) 1.2 m, real bigger inverted, 15 cm (6) 108 cm same side as the object, virtual and erect, 24 cm (7) 5 D (8) 30 cm, virtual erect, 1 cm (9) 6.7 cm (10) 40 cm in front of lens (11) 30 cm (12) 30 cm (13) −0.6 m (14) 33 cm (15) 12 cm, virtual erect; 12 cm, real inverted (16) −5, 2 (17) 1/2 (18) −1/3 or 1/3 (19) −1/3, 1/3 (20) −4, 4 (21) −10 cm (22) −10 cm (23) 12 cm, 20 cm left of lens (24) 20 cm (25) −2 m (26) 10 D (27) 70 cm left of lens.

CHAPTER 17

(1) 62.8 D, −0.068 (2) 3.3 cm (3) 20 D, 6.3 cm, 25 cm (4) 1.7 cm, 1.4 cm (5) 20 cm, 25 cm (6) 8 minutes (7) 20

CHAPTER 18

(1) -4×10^{-9} N (2) -2.3×10^{-12} N (3) 2.6×10^{12} (4) 4500 N (5) 90 cm (6) 2×10^{-10} C (7) 0N, 0N, 1.8×10^{6} N towards the positive charge (8) 6.25×10^{18} (9) 10^{8} C (10) 2.5×10^{-5} N, 1.6×10^{-3} N (11) Magnitude 24.3 $\times10^{11}$ N (12) 1325 NC^{-1} away from the nucleus, -2.1×10^{-16} N towards the nucleus(13) -1.6×10^{-14} N (14) 9×10^{-5} NC^{-1} (15) 20 cm (16) 9×10^{5} NC^{-1} towards the $-3\mu C$ charge (17) 30 N due north, negative, positive (18) 900 J (19) 4×10^{-7} J (20) $7\cdot2\times10^{9}$ J C^{-1}, 0 J C^{-1}, 0 J C^{-1} (21) 20 J, 1 J (22) -3×10^{4} V, 5×10^{4} V, -6.3×10^{4} V (23) -8.6×10^{4} V, 1.4×10^{-11} J (24) −20 V (25) 2 cm, -2.4×10^{-17} N (26) 8×10^{6} ms^{-1} (27) 45.5 V (28) 100 V (29) 0.54 A (30) 0.02 A (31) 1 A (32) 10^{19} (33) 1.6×10^{-2} A (34) 3.6 C (35) 300 V (36) 36.7 Ω (37) 0.38 A (38) 3 Ω (39) 0.25 Ω (40) 7 Ω, 6 Ω, 4 Ω, 4.5 Ω (41) 12 Ω, 0.125 A, 0.375 V across each resistor (42) 0.75 A (43) 0.1 A (44) Due south, due north, along positive x-axis (45) 9 Ω when in series, 1 Ω when in parallel (46) 10 V, 50 V, 75 V to 150 V, 500 V, 1000 V to 3000 V, above 3000 V (47) $9.98\times10^{10}\,\Omega$ (48) 10^{-13} A, 6.25×10^{6} (49) 9.6×10^{-19} J, 8.1×10^{-5} J (50) 0.05 C (51) 2, 1/9, 2, 1/4 (52) 2, 1/9, 4, 1/8 (53) Either both of them positive or negative, one of them positive other negative.

CHAPTER 19

(1) Due west (2) 2×10^{-3} N perpendicular to the plane of paper and coming out of it. (3) Perpendicular to the plane of paper ; going into it, coming out of it, coming out of it, going into it; towards left, towards right, downward, downward. (4) South will be attracted towards the wire (5) In the horizontal plane towards north (6) South, north.

CHAPTER 21

(1) 25 Ω (2) 25 W (3) Rs 1.92 (4) 1.5 A, 146.7 Ω (5) 121 Ω, 625 Ω (6) 4.5 A, 48.4 Ω (7) 1100 W (8) 125 V (9) 242 W (10) Rs 183.33 (11) 0.4, 4, 2 (12) 200 W (13) Rs 1.80 (14) 387 W, 1.76 A (15) 78 units (16) Rs 27.90 (17) 2.8×10^{5} J (18) 0.25 kWh, 1 kWh, 1.75 kWh (19) 1250 W, 312.5 W (20) 1 (21) 40 W, 80 W; 200 W; 30 min, 60 min, 150 min (22) 100 W (23) 16 h (24) 40 h (25) 0.025 kWh, 0.21 kWh, 0.3 kWh (26) 5 A, 10 A, 15 A (27) 250 W, 1000 W, 1250 W (28) 4 A, 9.24 A (29) No, yes, no (30) No.

O	Optical centre	—	—	D.16.19
P	Dioptric power	S	m^{-1}	D.16.28
	Power	S	Js^{-1}	D.5.3, D.21.2
	Pressure	S	Pa	D.8.1
PD, V	Potential difference	S	JC^{-1}	D.18.13
q, Q	Electric charge	S	C	D.18.2
Q	Heat transferred	S	J	D.13.6
r	Angle of reflection	S	radian	D.14.16
R	Radius of curvature	S	m	D.15.10
R	Reaumer	—	—	D.12.13
R	Resistance	S	$\Omega(VA^{-1})$	D.18.24
s	Specific heat capacity	S	Jkg^{-1}	D.13.4
	Distance	S	m	—
t, T	Temperature	S	Kelvin	D.12.3
u	Object distance	S	m	D.15.15
v	Image distance	S	m	D.15.16
V	Electric potential	S	JC^{-1}	D.18.12
	Volume	S	m^3	—
V	Volt	Derived SI unit	JC^{-1}	D.18.14
W	Water equivalent	S	kg	D.13.14
	Work done	S	J	D.5.1, D.18.10, D.21.1
W	Watt	Derived SI unit	Js^{-1}	D.5.4
Whr	Watt hour	Derived SI unit of energy	J	D.21.3
X	Neutral point	—	—	D.19.7
Y	Young's modulus	S	Nm^{-2}	D.11.32
Z	Atomic number	S	—	D.11.6
α	Coefficient of linear expansion	S	$°C^{-1}$ or K^{-1}	D.12.18
β	Coefficient of superficial expansion	S	$°C^{-1}$ or K^{-1}	D.12.20
γ	Coefficient of cubic expansion	S	$°C^{-1}$ or K^{-1}	D.12.22
γ_a	Coefficient of apparent expansion	S	$°C^{-1}$ or K^{-1}	D.12.24
γ_r	Coefficient of real expansion	S	$°C^{-1}$ or K^{-1}	D.12.26
θ	Temperature	S	K	D.12.3
θ_i	Angle of incidence	S	radians	D.14.15
θ_r	Angle of reflection	S	radians	D.14.16
	Angle of refraction	S	radians	D.16.5
μ	Relative refractive index	S	—	D.16.7
ϕ	Electrostatic potential energy	S	J	D.18.11
	Work function	S	J	D.20.7
ρ	Specific resistance	S	Ω	D.18.27
Ω	Ohm	Derived SI unit	VA^{-1}	D.18.25

Revision in Physics is a two volume book written primarily for Class IX and X students offering the All India Secondary School Certificate and Delhi Secondary School Certificate physics paper. It is an excellent book for ICSE students also. It provides useful material for students appearing in the Junior Science Talent Examination.

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